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MECHANICAL IMPACT SYSTEM DESIGN FOR
ADVANCED SPACECRAFT (MISDAS)

PHASE I--DESIGN CONCEPT SELECTION

September 20, 1965   Contract NAS 9-4915

N67 14888

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Project Manager MISDAS

L A Harris

L. A. Harris
Director, Structural Sciences

NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION
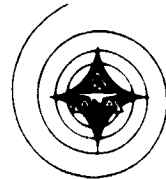
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FOREWORD

This document presents the results of Phase I, DESIGN
CONCEPT SELECTION, of a study of MECHANICAL IMPACT
SYSTEM DESIGN FOR ADVANCED SPACECRAFT. The study is
being conducted by the Space and Information Systems
Division of North American Aviation, Inc., under
Contract NAS 9-4915, with the Manned Spacecraft Center,
National Aeronautics and Space Administration, under
the technical cognizance of J. McCullough of the
Mechanical and Landing Systems Branch, NASA/MSC. This
report was prepared by A. I. Bernstein, Project Manager,
NAA/S&ID. Major contributors were D. A. Reed Jr. and
E. G. Clegg, Design Engineers, J. Partin, Dynamics
Engineer, and R. E. Snyder and A. Kusano, Structures
Engineers.

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TECHNICAL REPORT INDEX/ABSTRACT

ABSTRACT

The primary objective of this study is the design of a mechanical impact attenuation system for earth landing of advanced Apollo-type spacecraft. The system is to be adaptable to Apollo with minimum modification, and must absorb landing impact, protect crew and structure from excessive forces, prevent overturning of the spacecraft, and be reusable with minor refurbishment.

Phase I, reported in this document, has consisted of initial design, stability, and structural evaluations of ten concepts. The analyses have led to the recommendation of a six-segment heat shield design which satisfies the system performance criteria at minimum weight and minimum modification to the Apollo primary structure. Phase II will be a more detailed analysis of this concept.

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CONTENTS

ILLUSTRATIONS

TABLES

SUMMARY

The Space and Information Systems Division (S&ID) of North American Aviation, Inc. (NAA), under contract to the National Aeronautics and Space Administration, Manned Spacecraft Center (NASA/MSC) has initiated the development of an earth-landing system for advanced Apollo-type spacecraft. The design goal of Contract NAS 9-4915 is a landing impact-absorption system which can be incorporated in the Apollo command module with minimum structural modification, will provide a stable landing platform, will prevent vehicle overturning and damage to the structure, and can be reused with minimum refurbishment after each landing. The study, which encompasses preliminary design and limited stability analyses of candidate systems, is concerned with mechanical systems, i.e. devices which require contact with the landing surface to absorb impact energy.

In Phase I of the study, a mechanical impact system which will best satisfy the program objectives has been selected and defined. The concepts studied included one suggested by NASA and nine proposed by the contractor. The major technological problem was imposed by the requirement that the spacecraft shall not turn over when landing at any critical combination of horizontal velocity up to 80 feet per second, descent velocity up to 15 feet per second, and touchdown attitude up to 42 degrees (suspension angle plus pitch angle plus ground slope). After considering concepts involving displaced heat shields, extended skids, extended legs, airplane-type landing gear, inflated air bags, and crushable structural components, the following ten concepts, shown on Figures 1 to 10, were selected for preliminary evaluation.

  (a)   Chordwise-Deployed Skids
  (b)   Radially Deployed Skids
  (c)   Tricycle Gear Side Landing
  (d)   Forward-Extended Double Shoes
  (e)   Implanted Anchor
  (f)   LEM-Type Four-Legged Gear
  (g)   Four-Segment Extendable Heat Shield
  (h)   Forward-Translated Heat Shield
  (j)   Extended Heat Shield/Airbag
  (k)   Two-Segment Translated Heat Shield

Three concepts (d, h and k) were eliminated for instability under side wind conditions. One new concept, a six-segment hinged heat shield variation of concept (g) was formulated. These eight concepts were laid out to scale to assure that they fit in the limited space available outside the command module structure, to show where Apollo equipment must be relocated, and to identify modifications required for the Apollo heat shield or primary structure. Preliminary stability analyses have been conducted to define the overturning stability envelope of the spacecraft in terms of velocity, spacecraft attitude, and soil conditions. The

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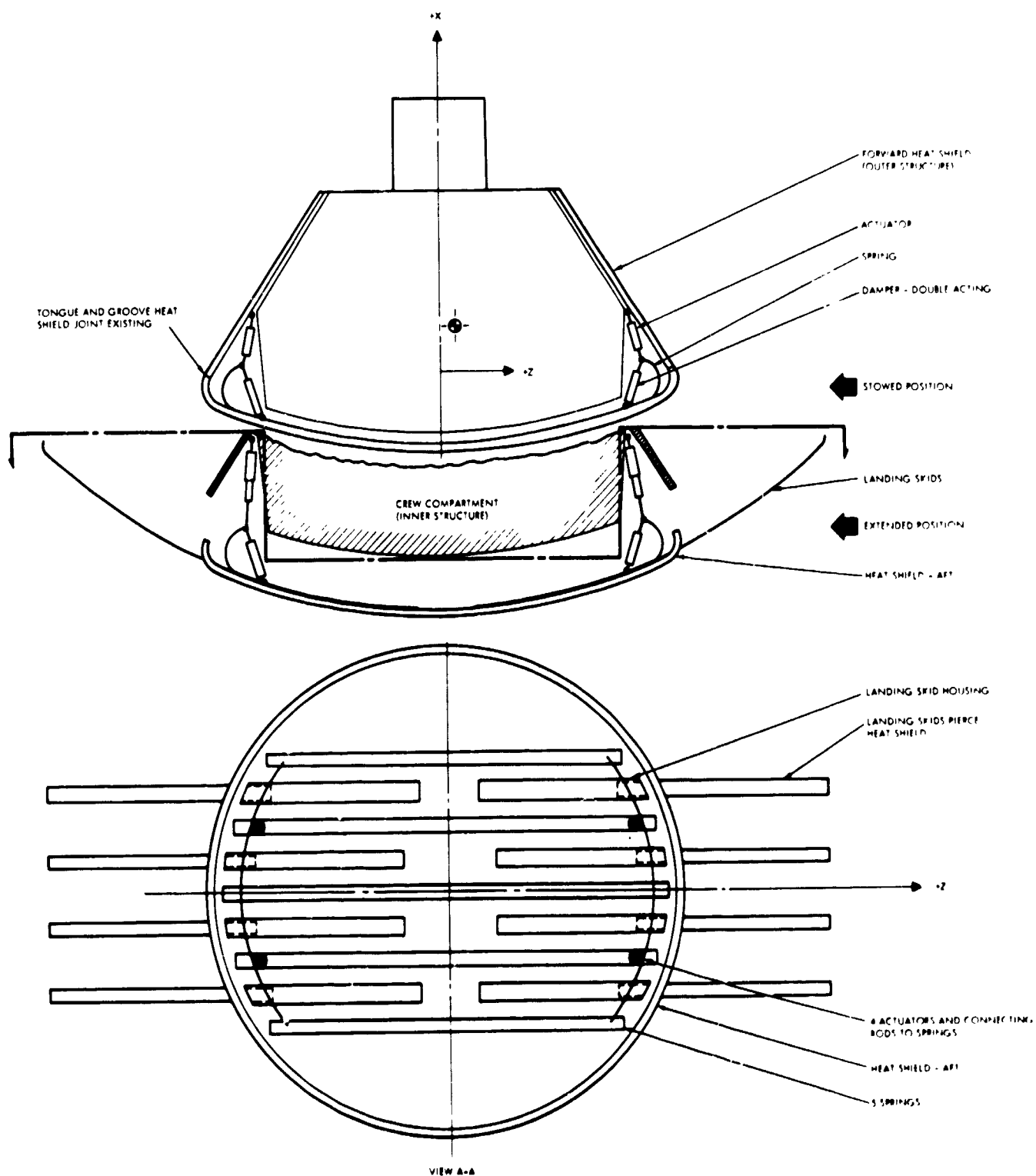
Figure 1   Concept (a) Chordwise Deployed Skids

LANDING SKIDS PIERCE HEAT SHIELD

LANDING SKID HOUSING

SHOCK STRUT

ACTUATING MECHANISM CONNECTED TO INNER STRUCTURE

+X

+Z

LANDING SKIDS

LOWER HEAT SHIELD EXTENDED
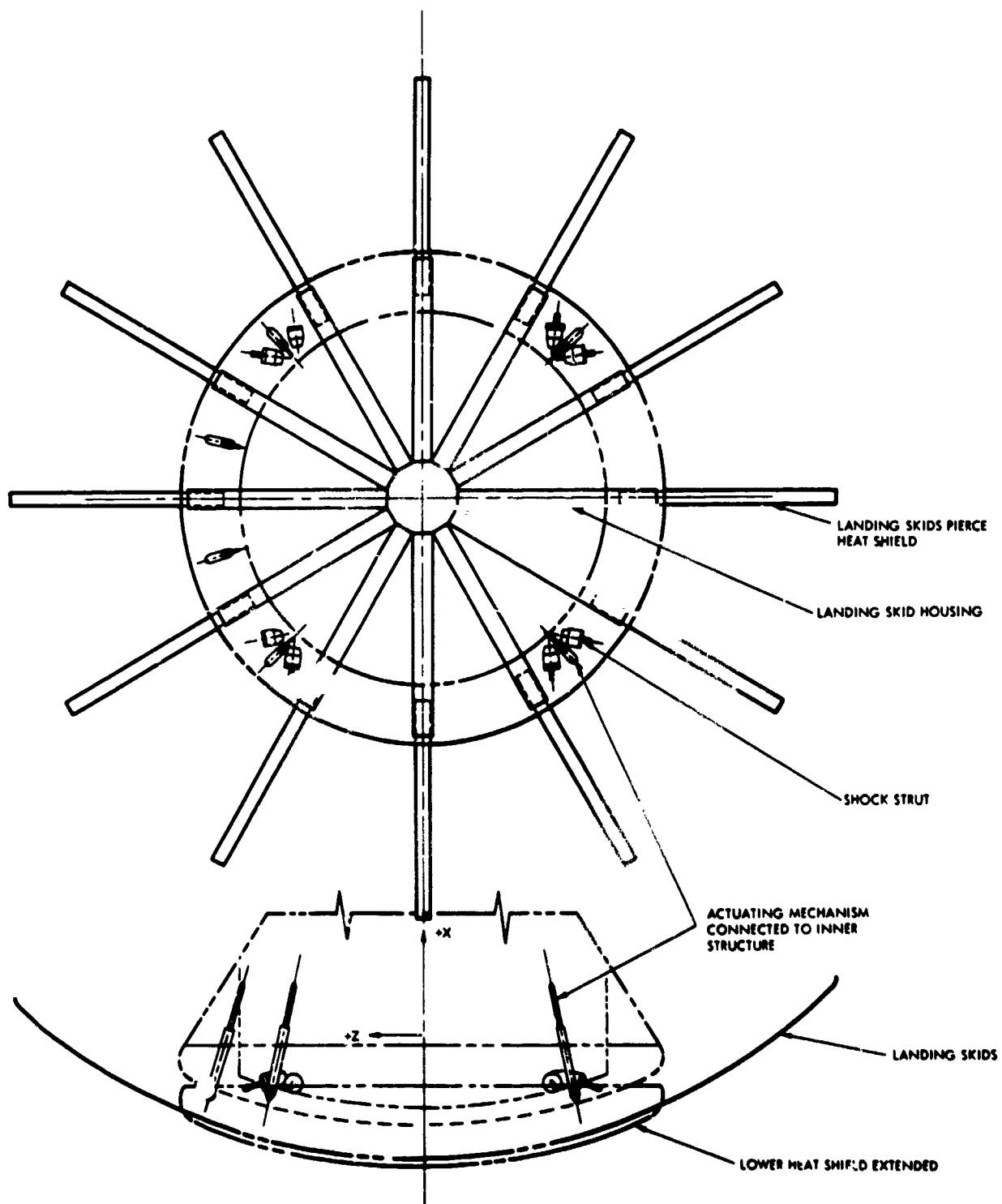
Figure 2   Concept (b) Radially Deployed Skids
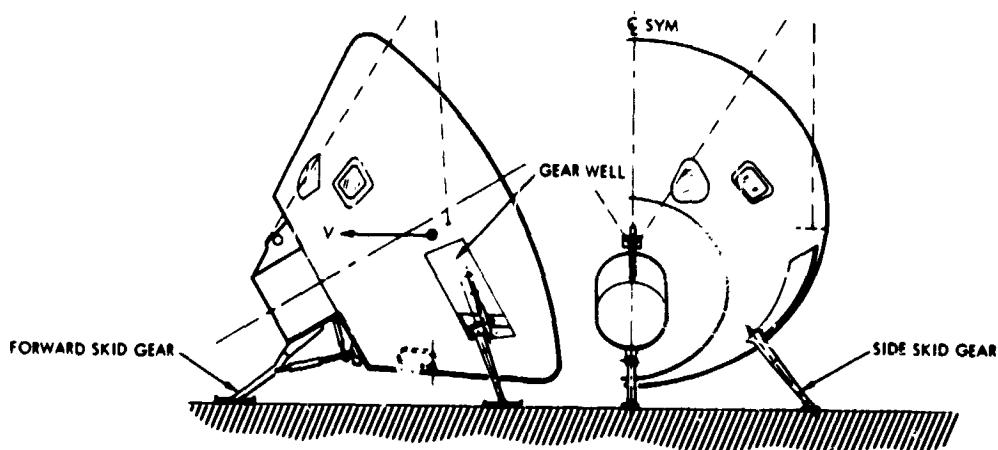
Figure 3   Concept (c) Tricycle Landing Gear
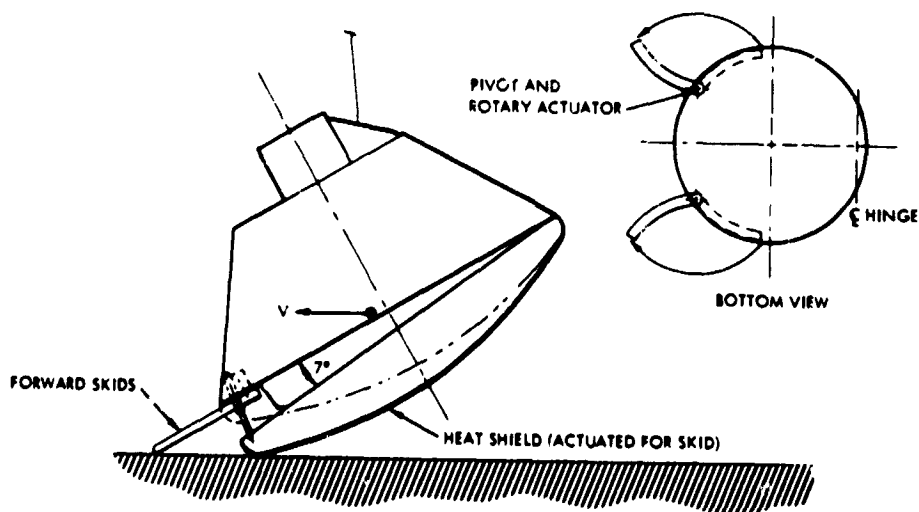
Figure 4   Concept (d) Forward Extended Double Shoes
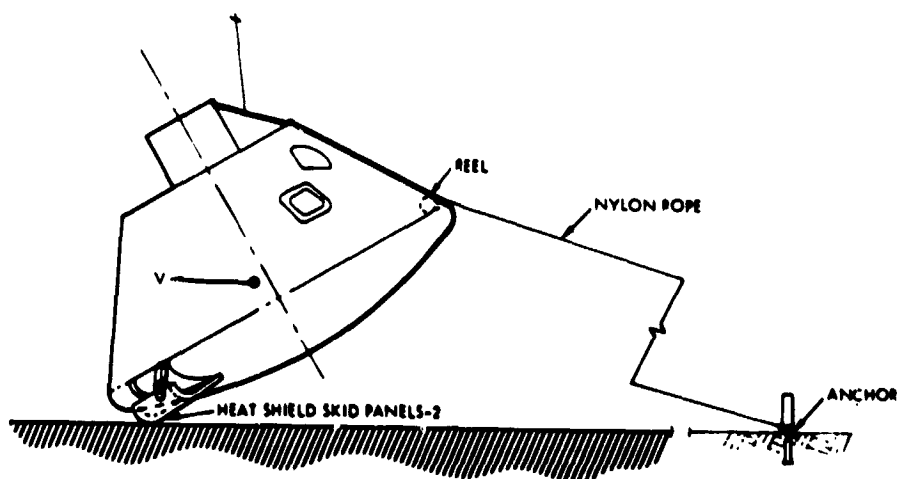
Figure 5   Concept (e) Implanted Anchor
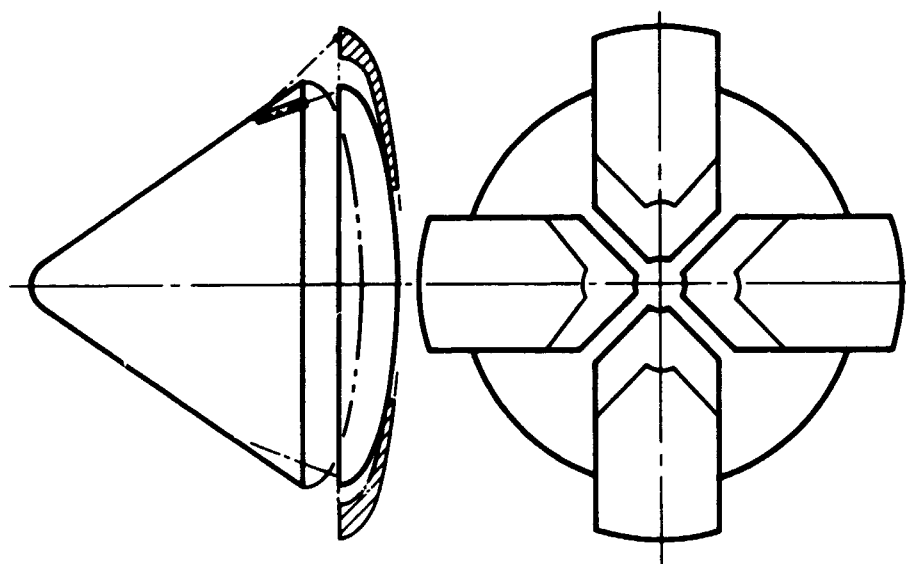
Figure 7 Concept (g) Four-Segment Extended
Heat Shield
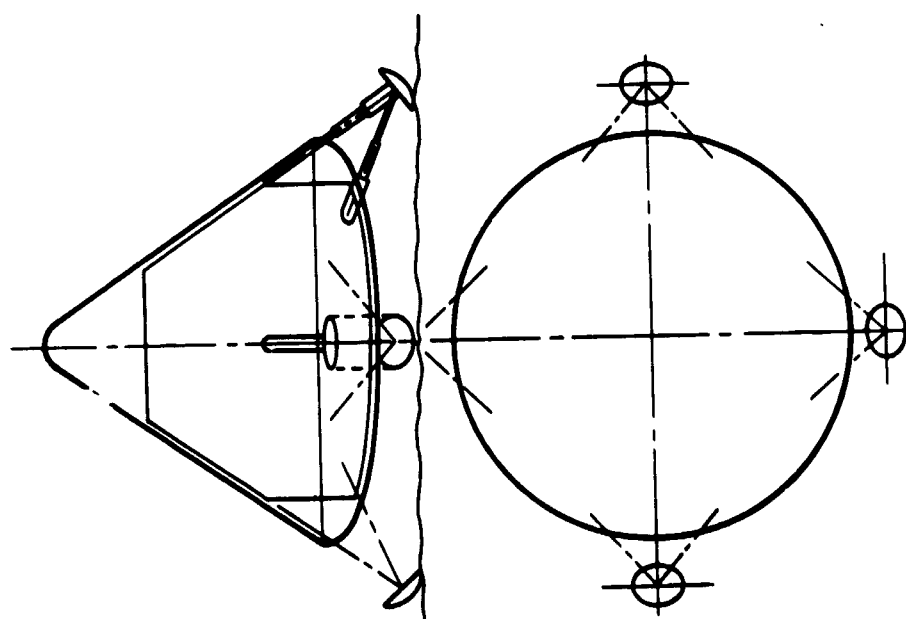
Figure 6 Concept (f) LEM-Type Four-
Legged Gear

-5-

Figure 10 Concept (k) Two-Segment Translated Heat Shield
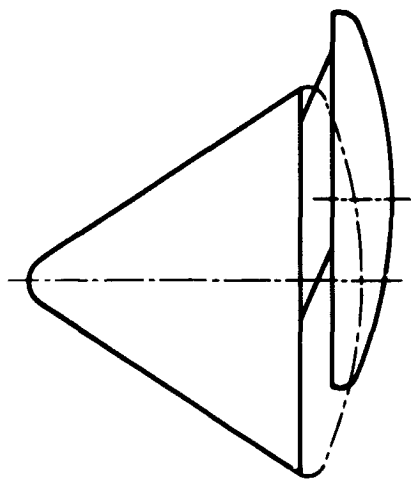
Figure 8 Concept (h) Forward Translated Heat Shield
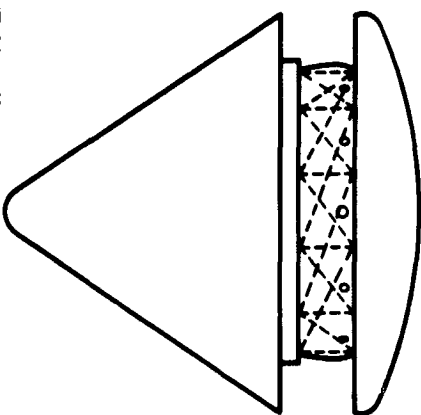
Figure 9 Concept (j) Extended Heat Shield/ Air Bag

stability analyses were based on a two-body, three-degree of freedom model, considering all components as rigid bodies, and assuming a non-deforming ground surface. Structural and weights analyses were conducted to define member sizes and materials, weight and volume requirements, and effect on the Apollo structure.

These analyses have resulted in the elimination of those concepts which could not satisfy stability, weight, or volume criteria. The remaining concepts were compared for relative weight, volume, design efficiency, simplicity, and compatibility with Apollo.

Based on the Phase I studies, the contractor recommends the detailed study of a six-segment hinged heat shield design. This concept shown on Figure 11 uses segments of the heat shield as landing skids. Each segment is hinged at two places on its inner edge, and contacts the ground on its toroidal section. A single vertical strut on each segment provides for deployment and landing impact attenuation. This design weighs 610 pounds, requires a volume of 1.6 cubic feet, is stable up to at least 100 ft/sec. horizontal velocity in all directions.
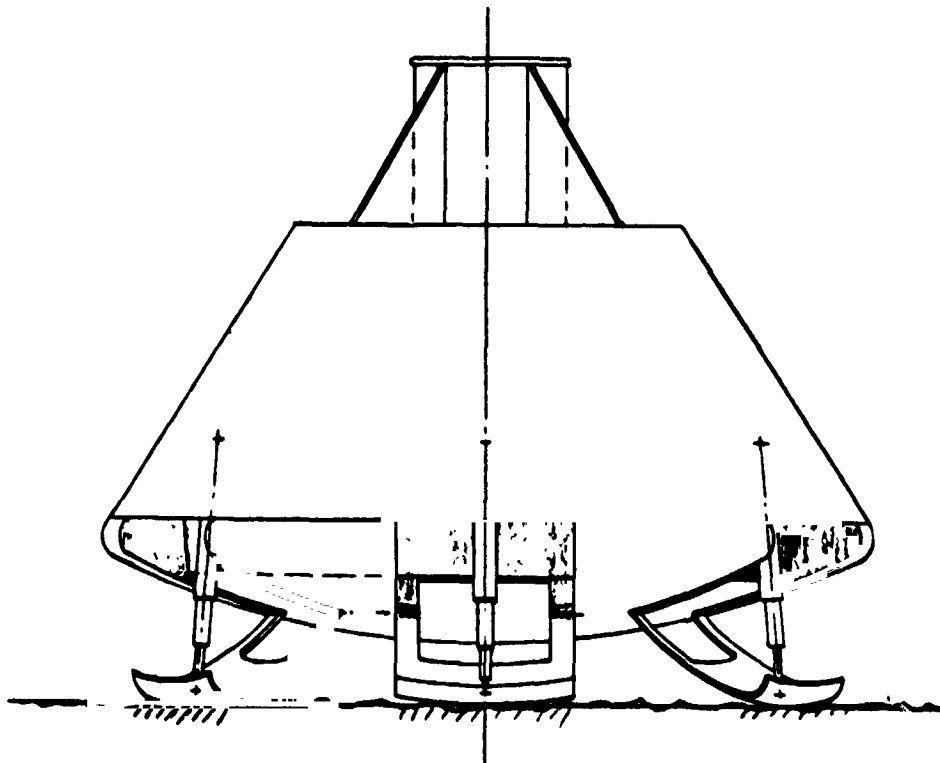
Figure 11   Pictorial View of Six-Segment Hinged Heat Shield Concept

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TECHNICAL OBJECTIVES

Future National Space Program missions will call for routine operational use of reentry vehicles which have enough maneuverability to make land landings at selected recovery sites and which can be reused with minimum refurbishment. The entry vehicles must be designed for normal and emergency landing on surfaces of varying slope, uniformity, and mechanical properties, and at critical combinations of vertical and horizontal velocity as dictated by local wind conditions and by the capability of future recovery systems utilizing Para-sails or other glide chute concepts and retrorockets to limit the descent velocity. Furthermore, the landing systems must provide stable landing conditions and must protect the spacecraft and crew from excessive load factors.

The design of a mechanical impact system for the Apollo command module is the objective of this study. In addition to satisfying the criteria noted above, the system must fit within the space available between the structure and heat shield and should involve minimum modification of the command module structure. The attempt to incorporate a reliable, practical mechanical impact system for earth-landing the Apollo imposes the following major design problems:

- The system must not turn over on landing.

- The system must absorb landing impact energy without subjecting the structure, crew, or payload to excessive accelerations.

- The system must fit within the limited space available between the Apollo heat shield and structure.

- The system should satisfy current state-of-the-art standards for simplicity, reliability, and minimum weight.

The design and analysis of the Mechanical Impact System is being accomplished as a two-phase program. Phase I, which is the subject of this report, encompasses the formulation of ten candidate design concepts, a preliminary tradeoff evaluation of these concepts, and the selection of one concept for more detailed study. The Phase I studies include:

- Selection of specific design criteria for landing conditions, system performance, soil mechanics, and material properties, to provide a common basis for system tradeoffs.

- Design analyses to evaluate impact system weight and volume requirements, relative design efficiency, reusability, and required modification to Apollo.

- Preliminary stability analyses to determine the landing stability envelope of each concept.
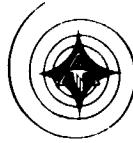
- Structural analyses to determine size, weight, volume, and materials required for each concept and the need for structural changes to the Apollo command module.

The evaluations were carried far enough to screen out unstable or otherwise undesirable designs. In all cases the technical analyses which justify the elimination of specific candidate concepts are presented in this report. Of those concepts capable of satisfying the design criteria, one was selected for further study on the basis of weight, colume, required modification to Apollo, design efficiency, and reusability.

Phase II will consist of a more refined design, stability, and stress analyses of the selected concept. The mechanical impact system will be defined, the members sized, and the materials and types of construction identified, and the stability envelope of the vehicle will be established. Required modification to the Apollo structure will be determined for the design conditions and for higher rates of descent (20 fps and 30 fps). A program plan and schedule for detail design, development, and qualification of the proposed system will be prepared.

SYSTEM SELECTION CRITERIA

Selection of an optimum design for the mechanical impact system followed the step-by-step screening and tradeoff analysis illustrated in Figure 12. The first step was the generation of a large number of designs with the potential ability to fulfill the performance, stability, weight, volume, reliability, and interface criteria noted on pages 12 to 15 . Of the many concepts considered, ten were selected for quantitative analysis. These concepts were then subjected to a series of screening tests to eliminate those which could not satisfy the stability, volumetric, or weight requirements.

The concepts found to be feasible were then analyzed parametrically. Where the analyses showed the need or desirability for design changes to improve the concept, the changes were incorporated in the study. The relative design efficiencies were compared, employing the following point scale:

Item		Points
(a)	Impact system weight	15
(b)	Impact system volume	10
(c)	Stability envelope	25
(d)	Design reliability and efficiency	15
(e)	Required modification to Apollo	10
(f)	Reusability	10
(g)	Required refurbishment	10
(h)	Effect of increased rate of descent	5
	Total	100

For each item in the tradeoff analysis, the concept which best satisfies that criterion is assigned the full number of points. The other concepts are assigned partial scores commensurate with their relative standing. For Items (a), (b), and (c), these point scores are assigned in proportion to the relative weight, volume, and stability envelope, respectively. Item (d), the design reliability and efficiency evaluation is based on number of mechanisms, requirements for explosive devices and shaped changes, discontinuities in the heat shield, system redundancy, and effects of component failure. Items (e), (f), and (g) are based on the relative requirements for relocating Apollo equipment, reinforcing structure, modifying the heat shield, and replacing parts worn or damaged in landing. Item (h) is based directly on the weight and volume penalties imposed by increasing the descent velocity to 20 and 30 feet per second.

Thus, the relative point-scores show, on a weighted average basis, how the candidate concepts compare on the basis of weight, volume, stability, efficiency, compatibility with Apollo, reusability, and growth potential. These criteria provide a guide to the selection of a design for detailed analysis.
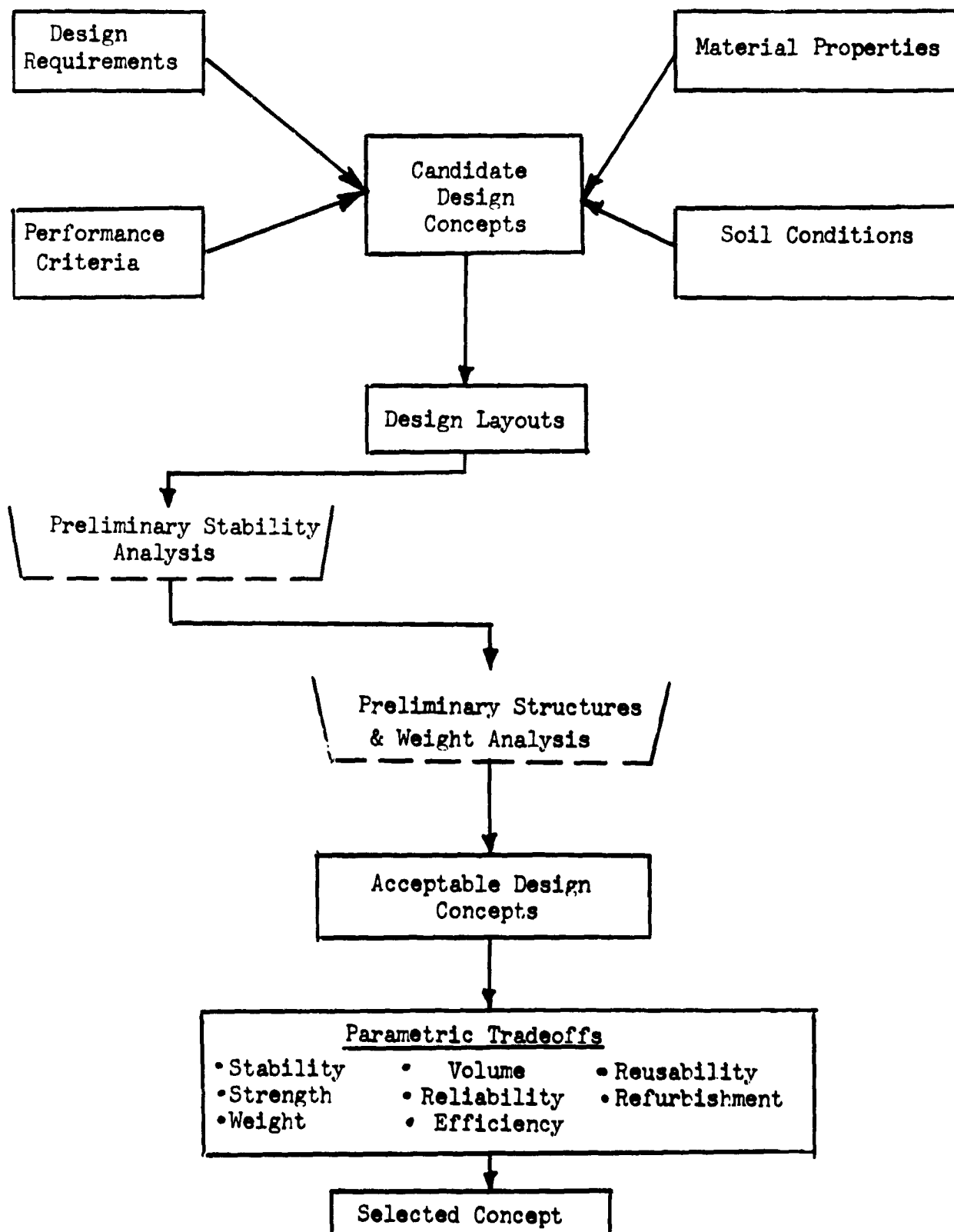
Figure 12   System Selection Logic

-11-

GUIDELINES, CONSTRAINTS, AND DESIGN CRITERIA

In order to establish a common baseline for the parametric evaluation of the candidate design concepts, the specific guidelines, constraints, and design criteria listed below were established. These criteria define the basic spacecraft geometry, landing conditions, stability requirements, acceleration limits, vehicle performance, ground surface properties, and material properties used in the study.

DESIGN REQUIREMENTS

1. The system will require contact with the landing surface to absorb impact energy.

2. It will be stowed during flight and deployed prior to landing.

3. Deployment time is not to exceed 30 seconds.

4. The system shall be designed for maximum reliability, simplicity, and efficiency.

5. The vehicle shall not overturn during landing and shall not sustain any structural damage.

6. The established crew tolerances for impact accelerations and onset rates shall not be exceeded.

7. Design shall be compatible with the Apollo structural drawings so that a minimum of structural modification is required for stowage and to support loads during impact.

8. The design shall be optimized for minimum weight and stowed volume. It is a design goal to restrict the impact system weight to 3.5% of the total landing weight of the spacecraft.

9. No part of the system shall be located inside the crew compartment.

10. The energy absorbing portion of the system can be designed for minor refurbishing after each landing.

11. Ultimate design loads for the system will be 1.33 times greater than those experienced while landing under the worst combination of the following performance criteria.

PERFORMANCE CRITERIA

1.	Vehicle landing weight	14,000 lbs.
2.	Rate of descent	0 to 15 ft/sec
3.	Horizontal velocity	0 to 80 ft/sec
4.	Landing surface	Soil
	a. Ground slope	± 5 degrees
	b. Holes and proturberances	± 3 inches
5.	Spacecraft attitude	
	a. Roll	± 10 degrees
	b. Pitch	± 10 degrees
	c. Yaw	± 10 degrees

It shall be a design goal for the system to accommodate landings of a roll angle of 180 degrees (backwards).

	d. Suspension angle	27 degrees

The present suspension angle can be changed only to improve substantially the landing system performance.

Figure 13 shows the basis for the horizontal velocity and spacecraft attitude criteria. This graph has horizontal velocity plotted as a function of spacecraft alignment with the wind direction (roll). This assumes emergency wind conditions of 51 ft/sec and a parachute L/D of 1, which provides a horizontal velocity of 30 ft/sec.

The shaded area of the curve represents the normal landing conditions. At zero degree roll, or direct alignment into the wind, the horizontal landing velocity would be 81 ft/sec, while the vehicle landing at 180 degrees roll, or against the wind, would have a backward velocity of 21 ft/sec.

The landing system designed under the subject contract shall accommodate all combinations of horizontal velocities and wind alignment conditions shown on this curve, in addition to the reserve chute landing conditions. Descending on the reserve chute, the vehicle can land at a horizontal velocity of 51 ft/sec, with roll attitude random with respect to wind direction.

SOIL CONDITIONS

All translational motion after initial contact is assumed to be in the form of skidding or sliding, acting parallel to the ground surface. No rebound,
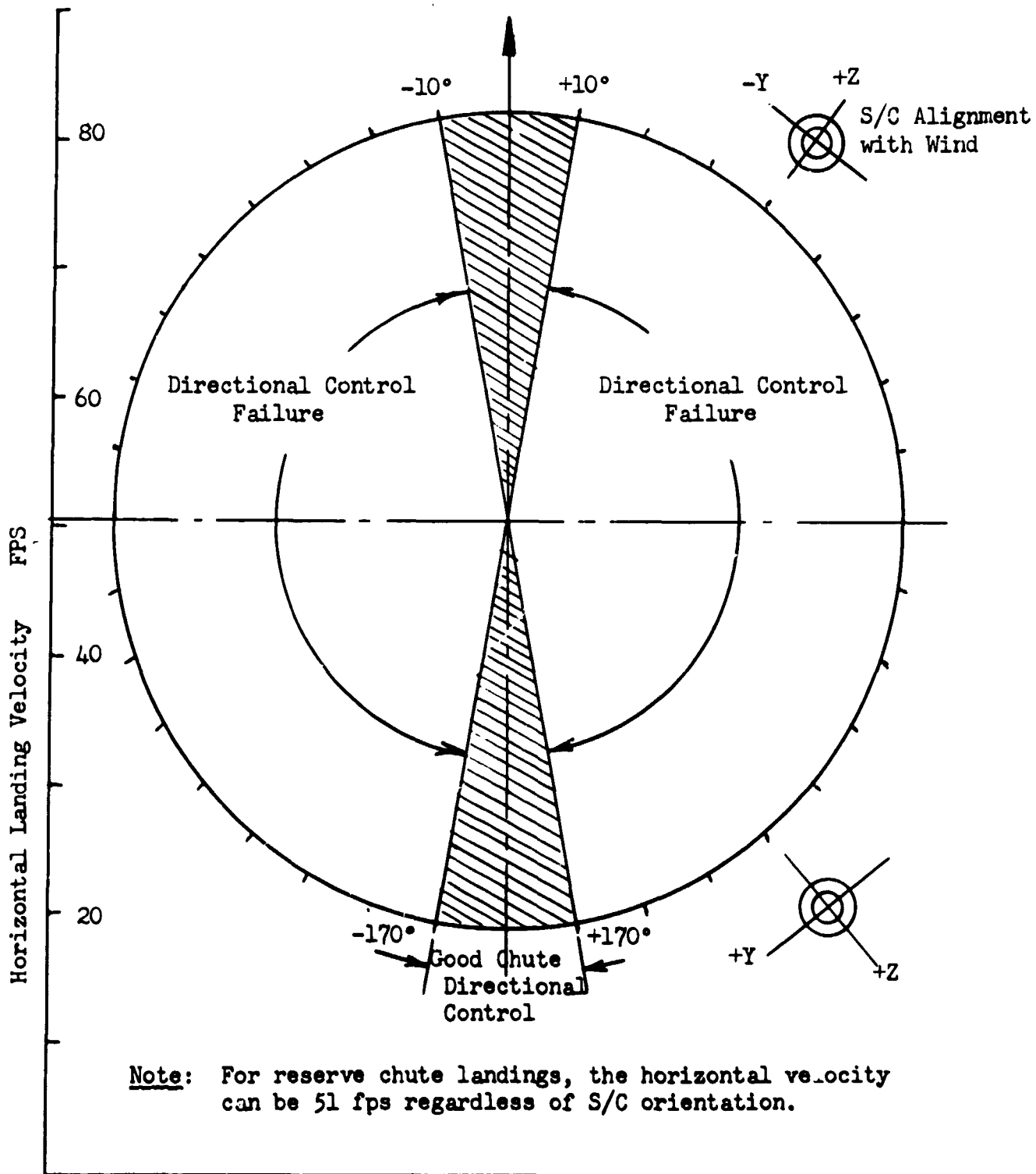
SID 65-1205

Figure 13   Effect of S/C Alignment with Wind on Horizontal Velocity

vehicle deflection, earth cratering, or variation in the coefficient of friction during the landing sequence is considered. The following parametric values of coefficient of friction are to be used:

0, 0.25, 0.50, 0.75, and 1.0. The stability of each concept will be determine for each of these values.

MATERIAL PROPERTIES

The mechanical and physical properties of structural materials shall be the guaranteed minimum values as given in the following documents:

MIL-HDBK-5, November 1964 revision, (Reference 1).
MIL-HDBK-17, June 1965 revision, (Reference 2).
S&ID Structures Manual, S&ID 543-G-11, revised December 15, 1964, (Reference 3).

PRELIMINARY DESIGN EVALUATION

At the onset of this program, the ten design concepts shown on Figures 1 to 10 were selected as potential candidate mechanical impact attenuation systems for Apollo earth landings. These concepts were chosen following consideration of designs which utilize combinations of deployed heat shields, extended skids, extended struts, aircraft landing gear, air bags, and crushable structural components. Three of these concepts, the forward-extended double-shoe (Figure 4), the forward-translated heat shield (Figure 8), and the two-segment translated heat shield (Figure 10) were eliminated from further consideration because they have no inherent resistance to overturning under side-wind conditions. One new design concept, which features six segments of the heat shield hinged to the basic heat shield structure, was generated.

The eight designs were laid out to scale to determine whether the impact system can fit into the available space between the command module structure and heat shield, to identify Apollo equipment which must be relocated, and to show required modifications to the Apollo structure or heat shield. These eight concepts are described in detail in the following paragraphs.

DEPLOYABLE HEAT SHIELD/CHORDWISE EXTENDED SKIDS

Concept 5260-1 (Figure 14) embodies a deployable aft heat shield to which are attached eight chordwise (in the directions of travel) deployable skids to prevent overturning. The landing impact is attenuated by a series of springs and shock absorbers located between the aft heat shield and inner body structure, and by friction of the heat shield skidding on the ground.

System Physical Description

The hardware consists of a modified aft heat shield with provisions for four rectangular tubes and eight gas-operated extendable skids. The system further includes a series of heat shield-mounted studs equipped with gas operated separation nuts that attach the heat shield to the eight main inner body support fittings. To the skid-deployment tubes are attached eight shock absorbing springs and four combination actuator/gas-eleo shock absorbers. To the inner body end of the springs are eight fittings which permit the springs to extend from their stowage position to down-lock at heat shield deployment. The main power source consists of three cartridge-activated high pressure gas supplies. Associated timers, electronics, etc. comprise the remaining system components. The separation nuts on the heat shield attach studs are energized by a common source high pressure pyrotechnic gas supply. The nuts are designed to stroke the heat shield studs free of the inner-body support fittings.

LANDING SKID SECTI

SECTION A-A ROTATED 48°
SCALE - 1/4 SIZE

2

SIDE
VIEW

RCS PITCH ENGINES

45.50 (TYP)

37.75 (TYP)

3

TRACE OF INNER BODY STA X_c = 12.7061 ; R_c = 57.8390
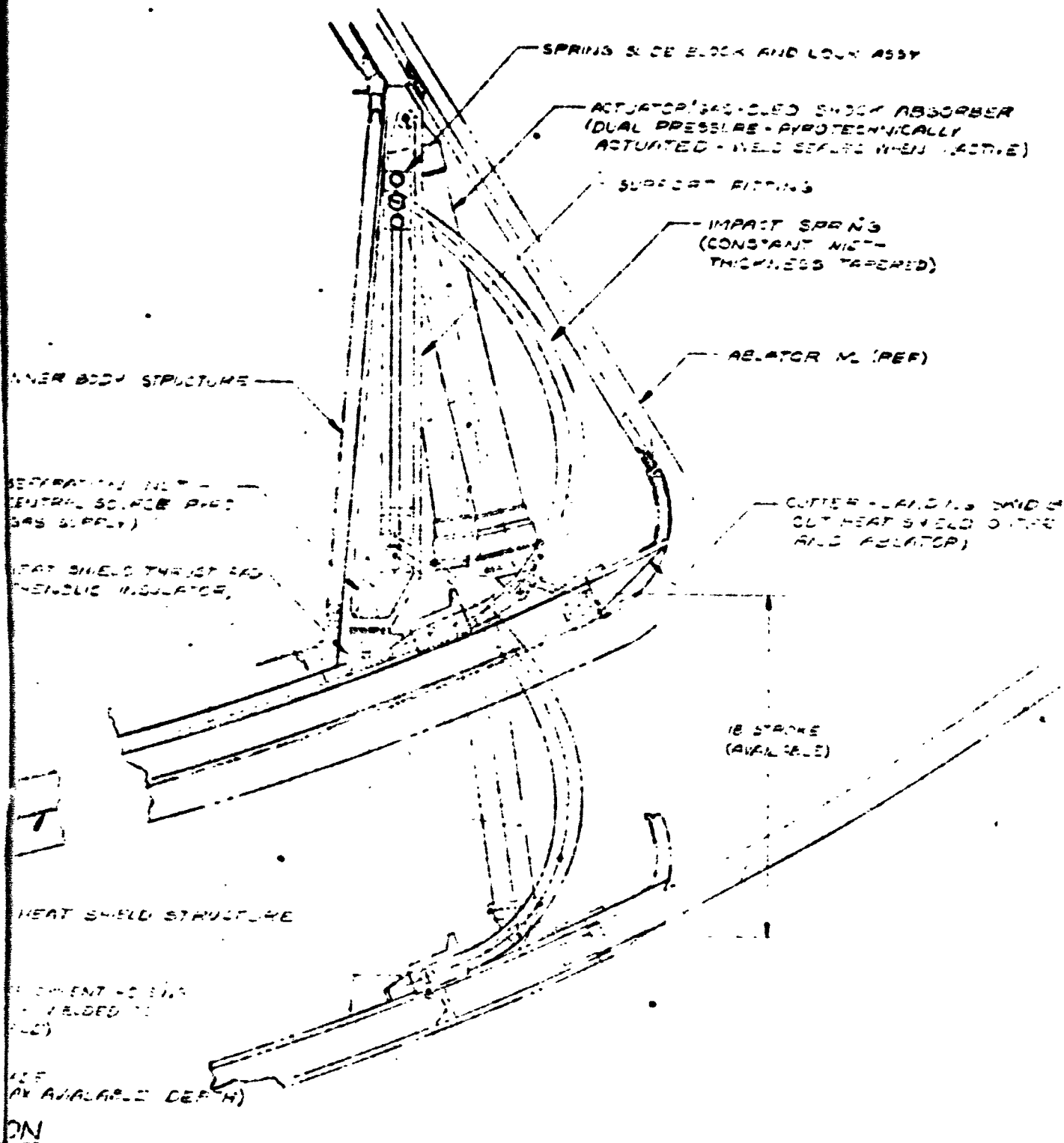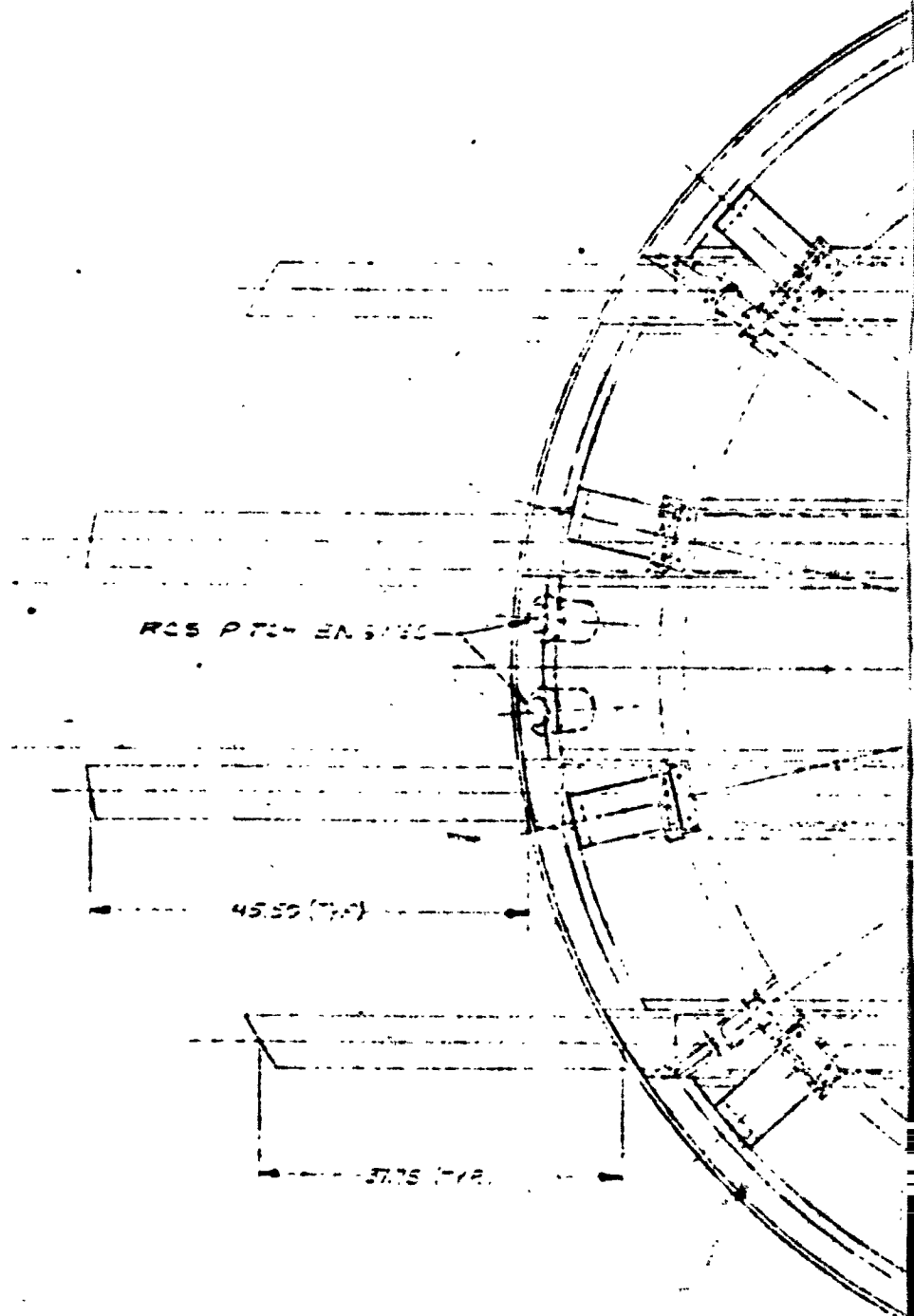
TRACE OF INNER BODY STA X_c = 43.1341 ; R_c = 60.3900

EDGE OF HEAT SHIELD STRUCTURE

RCS YAW ENGINES

HIGH PRESSURE FLOW METERING/CHECK VALVE
BLADE DEPLOYMENT SYSTEM A

HIGH PRESSURE FLOW METERING/CHECK VALVE
BLADE DEPLOYMENT SYSTEM B

SABOT SEAL

RCS FUEL TANKS (REPOSITION

BLADE SLIDE AND DEPLOYM

BLADE SUPPORT
(SUPPORT TUBE
OF THE HEAT S

WASTE

INNER E
AND SF

LANDING PAC

$+Z_c$

RCS OXIDIZE

A

A

POTABLE WAT

RCS OXIDIZER TANK
(REPOSITIONED)

HELIUM TANKS
(REPOSITIONED)

RCS YAW ENGINES

$+X_c$

VIEW LOOKING AFT
SCALE 1/16 SIZE

24

=0)

=ND SHOCK ABSORBER

' TUBE WITH REMOVEABLE END
S A STRUCTURAL MEMBER
- SKID)

JATER TANK (REPOSITIONED)
BODY SUPPORT FITTING
WING DEPLOYMENT GUIDE

SUT ATTENUATION SPRING

LANDING SKID BLADE
(DEPLOYED)
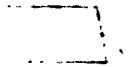
SKID ARM DEPLOYMENT STROKE
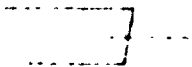
R TANK (REPOSITIONED)

NDION ABSORBER
TUBE SUPPORT FITTING
STRUCT)

SKID TANK (REPOSITIONED)

DEPLOYED CO

5

GROUND LINE

CONFIGURATION AT TOUCHDOWN

FIGURE 14

6

MISCAS STUDY

-17.15-

In rapid sequence a second pyro-technic gas supply attached to the four actuators is fired. The high-pressure gas ruptures the burst diaphragm seals on the actuator. A second oleo system seal is broken and aft heat shield deployment of 18 inches is effected. This represents a practical upper limit of physical deployment of the heat shield for this type suspension system.

As the heat shield deploys, the inner-body end of each energy absorption spring slides in its guide, located in the support fittings, to a position of downlock. The downlock is a simple overcenter sliding lock which engages as the spring slides over a locking slot in the support fitting. The actuator stroke is greater than the spring slider motion and a lock-hold position is maintained as locking occurs. The deployment of the heat shield utilizes gas pressure sufficient to charge the actuator/gas-oleo strut for dampening action by the strut during landing impact. For emergency landings above standard a 'g' onset meter may fire additional pressure cartridges for additional impact attenuation near full actuator stroke. Alternatively, gas chamber volume ratio of the actuator can provide a variable spring rate on a fixed system basis.

Concurrently or sequentially a third pyro-technic gas supply is fired to extend the landing skids. The pressure is such as to permit the sharpened outer tip of the skid to puncture the outer structural wall and ablator of the heat shield. Due to an expected large differential force required to deploy the blades an attenuator is mounted in the blade support tube which stops and locks the blade in an extended position for a wide range of blade impact velocities.

Spacecraft Compatibility

The C/M inner body structure will require a major modification to install this system. Every system in the aft heat shield compartment will require relocation with the exceptions of the RCS engines and heat shield mounted antennae. The C/M to S/M tension ties may require redesign to permit the heat shield to be dropped. Currently the tension tie is continuous through the heat shield to the external longeron on the inner C/M structural wall. The C/M to S/M umbilical will require relocation. The heat shield structure is a new design. To obtain the maximum usefulness of the concept the parachute hang angle should be reduced to 0°.

Functional Considerations

The mechanical reliability of pyro-operated devices is a proven field. The skids may be marginal structurally in that a maximum bending thickness of from 1.50 to 2.00 inches is the "space available restriction" of the current C/M heat shield configuration. Deployment sequence is not restrictive in that any order of pyro-technic firing will always produce a successful system deployment. The requirement that the deploying skids must pierce and extend through the heat shield structure detracts from the overall design efficiency. However, the deployment system can be designed to very high safety factors, and backup provided for critical functional components to assure extension of the skids in event of single-component failure.

DEPLOYABLE HEAT SHIELD/RADIALLY EXTENDED SKIDS

Concept 5260-2 (Figure 15) embodies a deployable aft heat shield to which
are attached a series of radially deployed skids to prevent overturning. The
landing impact is attenuated by a series of shock absorbers located between
the aft heat shield and the inner body structure and by sliding friction of
the heat shield skidding on an unprepared area. Functionally, this concept
is identical to Concept 5260-1, discussed above. It differs from 5260-1 only
in the number and location of the extendable skids and their supports. The
radial deployment of the skids offers impact stability for crosswind landings
which is lacking in Concept 5260-1. However, Concept 5260-2 occupies a larger
volume, and therefore requires more extensive relocation of equipment than
Concept 5260-1. The discussion of system operation, spacecraft compatibility,
and functional considerations given above for Concept 5260-1 is directly
applicable to Concept 5260-2.

DEPLOYABLE HEAT SHIELD/FOUR-LEGGED GEAR

Concept 5260-3 (Figure 16) embodies a deployable heat shield and a four
strut landing gear assembly. The concept is a modified form of the LEM land-
ing gear system. The heat shield is deployed on four tripod landing gear
assemblies and from the main vertical strut of each tripod extends a landing
strut and furrowing disk assembly.

The furrowing disks are inclined to the landing strut in the radial plane
of the strut on a axel such that during lateral motion of the C/M, disks
ahead of the C. G. in the direction of travel will plane soil or water and
disks behind the C. G. will "furrow or plow" soil or water. The planing and
furrowing action of the gear occurs along any lateral vector throughout the
entire 360° lateral motion potential. The effect of the gear forces on the
motion behavior of the C/M is to provide a stabilizing pitching moment force
system to prevent overturning and a directionally stabilizing force system
about the landing vector to prevent yaw spinning at impact. The heat shield
is utilized as a force distribution structure which in turn minimizes the
size and weight of the tripod landing gear system.

System Physical Description

The landing system consists of four tripod strut assemblies, the C/M
heat shield, four struts and furrowing disks, a pyro-technic gas supply
pressurization system, a fully weld-sealed oil accumulator and liquid spring
shock attenuating system, and related electrical circuitry and structural
hardware.

Each leg of the landing gear tripod contains a remotely pressurized
liquid-spring gas-spring impact attenuator.

The outer cylinder of the vertical strut is attached to the inner body
of the C/M at Xc = 40.280 and Rc = 62.390. The intermediate cylinder of the
vertical strut is attached to the heat shield structure by a spherical bear-
ing and fitting at Xc = 16.706 and Rc = 64.838 (bearing center coordinates).
The inner cylinder of the vertical strut attaches to the 20- inch diameter
furrowing disk axle. The disk axle centerline is coincident to the heat
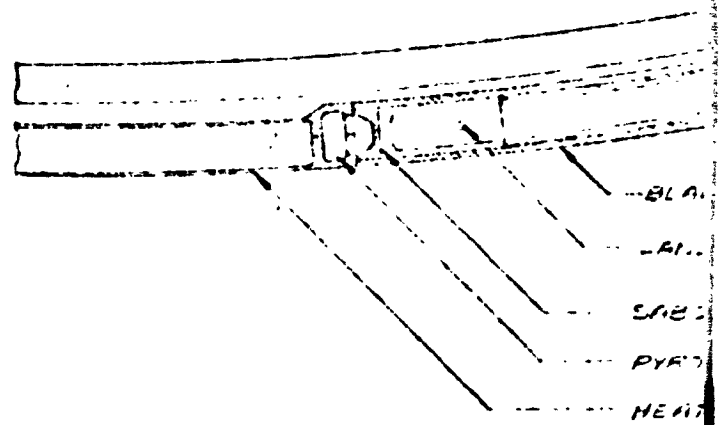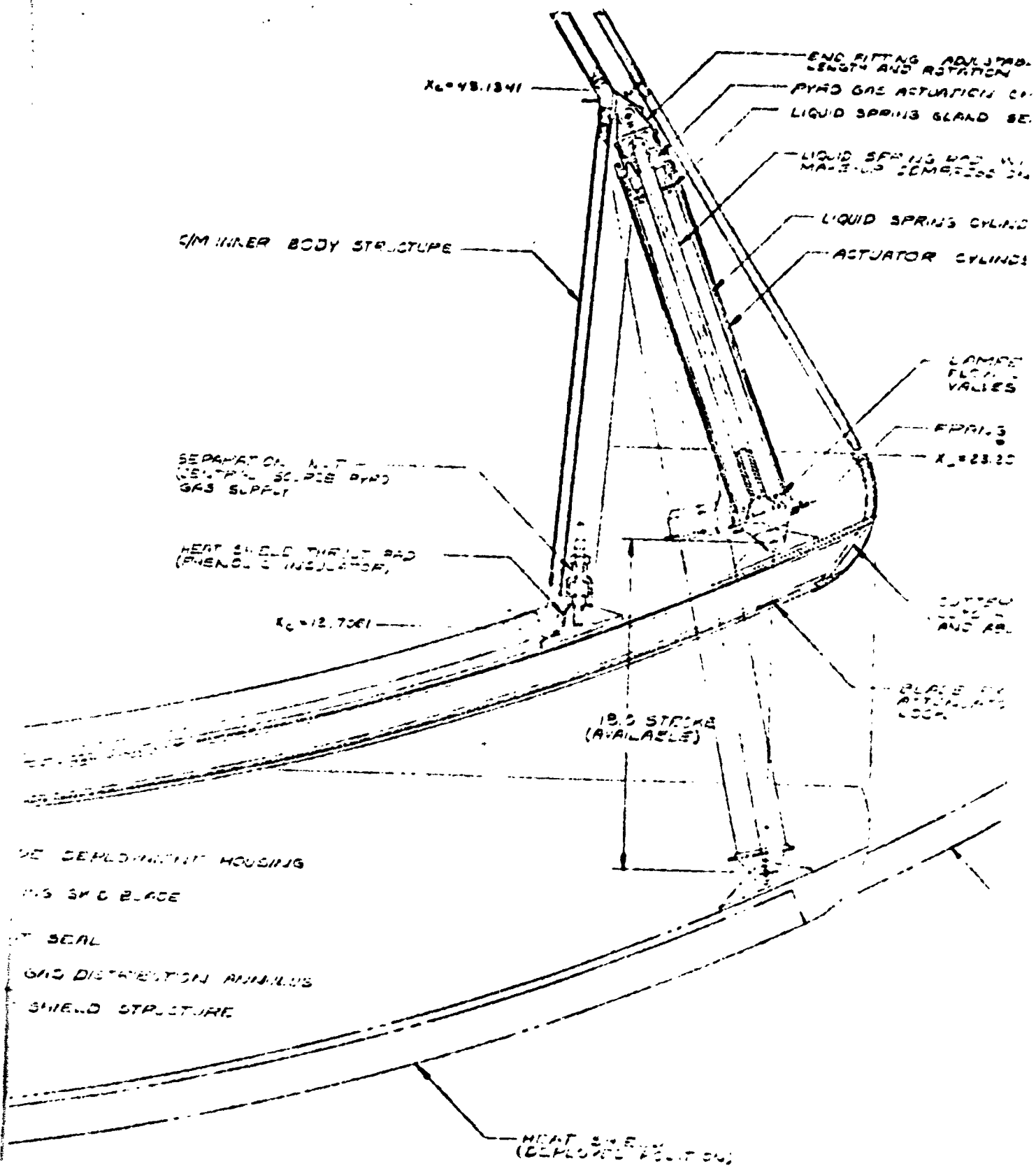
-20-

BL A.

AI..

SAE

PYF

HEAT

1

SECTION D-D
SCALE 1/4 SIZE

2

TRACE OF INNER BODY $x_c = 12.7061$, $R_c = 5$
TRACE OF INNER BODY $x_c = 43.1341$, R_c
HELIUM TANK (REPOSITIONED)
EDGE OF HEAT SHIELD STRUCT.
RCS YAW ENGINES
(REPOSITIONED)

3

VIEW LOOKING AFT
SCALE 1/3 SIZE

7 8380

30 3720

J45

FWD GAS SUPPLY LINE-
BLADE DEPLOYMENT
SYSTEM 'A'

RCS FUEL TANK
(REPOSITIONED)

LATERAL IMPACT ATTENUATORS

RCS FUEL TANK (REPOSITIONED)

LANDING SKID BLADE
(DEPLOYED)

BLADE SLIDE AND DEPLOYMENT
SHOCK ABSORBER

WASTE WATER TANK (REPOSITIONED)

VERTICAL IMPACT ATTENUATO

$+Z_c$

SABOT SEAL

RCS OXIDIZER TANK (REPOSITIONED)

112 50 R (PROJ)

RCS OXIDIZER TANK (REPOSITIONED)

WATER TANK (REPOSITIONED)

FWD GAS SUPPLY LINE:
BLADE DEPLOYMENT SYSTEM 'B'

2 4

RS

DEPLOYED CONFIGURATION AT TOUCHDOWN

GROUND LINE

FIGURE 15

#5

LATERAL MOTION SHOCK ABSORBER

OUTER CYLINDER
(REACTS LANDING DISK AND
HEAT SHIELD FORCES)

LATERAL MOTION SHOCK AB

INTERMEDIATE CYLINDER
(DEPLOYS AFT IN AT END
THROUGH A SPHERICAL ...

HEAT SHIELD ATTACH FITTING

HEAT SHIELD AT K=0

INNER CYLINDER EXTENS
(CONTAINS DUAL EXTENSION
SPRINGS ...

VIEW B-B ROTATED 22½°
SCALE - ¼ SIZE

2

SPHERICAL BEARING

HEAT SHIELD ATTACH F.

HEAT SHIELD
18 STROKE
(AVAILABLE)

SCREEN

EXTENDED POSITION
OF STRUT (FOR
A-A COMPRESSION)

DISK STRUT
16 STROKE
(AVAILABLE)

TO FEED
LIQUID

LANDING SKID C.F.
(ROTATES ON CANTED AXIS)

SECTION B-B ROTATED 22½°
SCALE · ¾ SIZE

3

TRACE OF INNER BODY

TRACE OF INNER

EDGE OF HE

RCS

'TTING

RCS PITCH ENGINES

VIEW LOOKING
SCALE - 1/10 SIZE

4

$x_c = 12.70m$; $R_c = 57.8380$
BODY $x_c = 43.1341$; $R_c = 60.3920$
AT SHIELD STRUCTURE

YAW ENGINES
HELIUM TANK (REPOSITIONED)
LANDING SKID DISK (STOWED POSITION)
LATERAL IMPACT ATTENUATOR
INNER BODY ATTACH FITTING
RCS FUEL TANK (REPOSITIONED)
WASTE WATER TANK (REPOSITIONED)
INNER BODY ATTACH FITTING - VERTICAL IMPACT ATTENUATOR
$+Z_c$
HEAT SHIELD ATTACH FITTING
RCS OXIDIZER TANK (REPOSITIONED)
OUTER CYLINDER - VERTICAL IMPACT ATTENUATOR
POTABLE WATER TANK (REPOSITIONED)
HELIUM TANK (REPOSITIONED)
RCS YAW ENGINES

$22\frac{1}{2}°$

DEPLOYED CONFIGURATION AT TOUCHDOWN

GROUND LINE

FIGURE 16

SCALE	DR.	NORTH AMERICAN AVIATION, INC.	
NOTED	DATE		
	MODEL		

DEPLOYABLE HEAT SHIELD/ 4 LEGGED
SEAT CONCEPT - MISDAS STUDY

5260-3

-23,24-   SID 65-1205

shield spherical radius and intersects the vertical strut centerline at $Xc = 12.700$ and $Rc = 65.463$. Internal to the inner cylinder is a double extension liquid spring piston and oil flow metering and check valve assembly.

The lateral force outer cylinders are attached to the inner body of the C/M at $Xc = 14.581$ and $Rc = 59.338$ $22\frac{1}{2}°$ each side of the main vertical strut. The inner cylinder of each lateral motion strut is attached to the fitting that houses the spherical bearing of the main vertical strut forming a stable tripod gear assembly. Internal to the inner cylinder is a single extension, pressure centering, liquid-spring piston and oil flow metering and check valve assembly. The lateral-force cylinders provide a reaction to resist extension or contraction of the strut from the initial landing geometry.

The heat shield is utilized to coordinate all vertical and lateral forces of the extended furrowing disk into more than one tripod assembly during impact. In addition the heat shield provides an impact structure when furrowing disks are temporarily bottomed during impact. The landing system when deployed provides for 16 inches of axial motion of the furrowing disk relative to the heat shield, and the tripods permit an additional heat shield axial motion of 18 inches along the C/M centerline and a lateral motion of 6 inch radius about the C/M centerline.

As designed, the landing system can absorb 30 f.p.s. vertical velocity only or a combined 15 f.p.s. vertical and 81 (or 51) f.p.s. velocity.

Spacecraft Compatibility

This concept will require a redesign of the C/M inner structure aft bay, the heat shield and the C/M to S/M tension tie system. Space is available in the aft bay to accommodate existing Apollo systems and the "furrowing disk" landing systems. All of the major components in the aft equipment bay will have to be repositioned to be compatible with the physical location of the struts. This includes the RCS propellant tanks, helium pressurant spheres and water tanks. The RCS motors will not have to be relocated.

Functional Considerations

At the landing system deployment signal, a pyro-technic gas supply attached to the heat shield separation nut system fires and releases the heat shield to C/M inner body attachment. Sequentially or simultaneously a second pyro-technic gas supply fires. The high pressure ruptures the systems burst diaphragm seal and pressurizes the liquid spring reservoir and the tripod and furrowing disk struts ruptures the welded frangible strut seals. Subsequent motion deploys the heat shield 18 inches along the C/M centerline and the furrowing disk struts 16 inches along the strut axis. The speed of deployment is regulated by the damper piston flow rate orifices at impact rebound rates (approximately 90% energy damped motion). The system will take approximately 4 to 10 seconds to deploy.

SID 65-1205

Impact due to vertical motion initially taken by the furrowing disks at a linear spring rate of 0.25g initial contact per strut to 1.87g per strut at 7" deflection when the center of the heat shield contacts the water or soil. The disks lift off at 1.87g per tripod and permit heat shield deflection along the C/M centerline to a maximum of 4.75g at the 11 inch heat shield deflected position. A vertical only impact of 15 f.p.s. will deflect the furrowing disks and heat shield a total distance of 8.50 inches (7 inches stroking of the disks and 1.5 inches heat shield) producing an average force of approximately 4.25g's and a maximum force of approximately 7.50 g's. The overshoot vertical only impact capability is linear to a maximum deflection of 25 inches and a maximum force of 25 g's.

The vehicle response to lateral motion or combined vertical and lateral motions at impact is dominated by furrowing disk behavior. The inclination of the disk to the impacted surface is such that soil relative motion in the direction of the radial plane of the disk strut from the disk toward the C/M centerline will produce a planing (up force) low coefficient of resistance (drag force) skid. When the relative motion is reversed 180°, so that relative soil motion is from the C/M centerline toward the forrowing disk, the disk will dig in or plow. This action will produce a down force and a high drag force resulting from dynamically intercepting and turning the soil in an action similar to the dynamic water brake of a track-guided sled test. A forward and aft located (relative to the lateral motion vector) furrowing disk combination therefore produces a negative overturn moment whose arm is equal to twice the distance from the disk centerline to the C/M centerline. When relative motion is along lateral vectors not in the plane of a furrowing disk pair, the behavior of lateral motion is maintained, since the force produced by the combined action of all four disks is a polar vector system of nearly uniform response.

It is probable that alternate six-disk and eight-disk systems of approximately the same system weight can be installed. The lateral struts of the tripods would be shared by the main vertical struts containing the furrowing disks struts. The resulting impact "kern" should become circularly polarized (for all practical purposes) and the minimum R/h parameter would increase by a factor of approximately 1.31.

FOUR-SEGMENT TRANSLATED HEAT SHIELD

Concept 5260-4 (Figure 17) consists of four equal segments of the heat shield which are deployed downward and translated outward to provide a base. The design shows the practical limit of deployed base diameter and vertical stroke that can be achieved with this concept. The suspension angle has been changed to zero degrees to provide an equal landing capability in all directions.

System Physical Description

Each segment is translated outward by an electrically-operated winch and cable, while the inboard corners of the segment slide in tracks inset in the

100

99.5

HEAT SHIELD SEGMENT
DEPLOYED

1

ATTENUATOR
(STOWED)

+Y

SLIDE
DEPLOYED

HELI
(REPOS

OXIDIZER
(REPOSIT

SEGMENT ACTUATOR

THRUSTER & VERTICAL
VELOCITY ATTENUATOR
(2 PER SEGMENT)

2

-Z

RCS PITCH MOT

90°
TYP

+Z

JM TANK
ITIONED)

TRACK

TANK
ONED)

3

HELIUM TANK (REPOSITIONED)

POTABLE WATER TANK (REPOSITIONED)

RCS YAW MOTORS

—Y

GROUND LINE

FUEL TANK (REPOSITIONED)

WASTE WATER TANK (REPOSITIONED)

LOOKING AFT ON
EQUIPMENT BAY
SCALE 1/2

DEPLOYED CONFIGURATION AT TOUCH-DOWN

FIGURE 17

*5

SCALE	DR.	NORTH AMERICAN AVIATION, INC	
	DATE	SPACE AND INFORMATION SYSTEMS DIVISION	
	MODEL		

FOUR SEGMENT TRANSLATED HEAT SHIELD CONCEPT, MIMAS STUDY

-27,28-   S.D.65-1205

inner bulkhead. Having reached the end of their travel, the sliders are locked in place by a simple spring-loaded sear mechanism. Two pyro-technic thrusters provide the downward movement for the outboard edge of each segment. At landing the segments hinge at the sliders on the inboard corners and the thrusters absorb vertical energy by functioning as oleo struts on the return stroke.

A base of about 200 inches is provided in the Y and Z planes. Since the deployed segments are in point contact with the ground, the base is slightly less when travelling in any other direction. A method of enhancing the stability in certain soils by the addition of soil scoops on the centerlines of the segments was considered. When skidding over the ground, the scoop on the leading segment is inactive, while the trailing scoop digs in throwing soil upward. This can only be accomplished at the expense of weight and complexity and therefore was not considered further.

Spacecraft Compatibility

The inner pressure structure will require major modification to install this concept. Eight attachments are required for the upper end of the struts. Tracks are required in the lower surface of the inner bulkhead, and the outboard ends of these must be capable of taking loads in all directions. This concept requires a center heat shield plug 40" diameter to be supported entirely by the inner bulkhead. A series of separation nuts joining the inner and outer heat shields which take the place of the existing 78 bolts could be used to increase the structural integrity of the heat shield assembly. However, much of the aerodynamic load would still be transmitted to the inner bulkhead. The spacecraft-parachute harness must be changed to provide a zero degree hang angle. Equipment in the aft equipment bay requires only minor relocation to clear the 8 struts. No change to the RCS motor location is required. In addition, the current three tension ties which locate and attach the C/M to the S/M must be revised to permit heat shield deployment. These ties will have to be cut between the attachment to the inner structure longerons and the heat shield.

The area of ablative material which must be sheared during segment deployment is greater in this concept than in any other. To avoid excessive forces in the actuators and thrusters, it will be necessary to employ a special technique at the mating surfaces.

Functional Considerations

This concept, while providing a desirable footprint, is complicated by the various mechanisms for deploying the heat shield segments. In addition, complicated structural requirements exist. Premature translation of the segments is considered an extremely remote possibility. The reliability of the thrusters and other pyro-technic devices is considered equal to the forward heat shield jettison and therefore should meet crew safety and reliability criteria. As with the forward heat shield jettison mechanism, dual cartridges and electrical circuits will be employed to enhance reliability.

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Servicing of components may be accomplished through the existing doors. Pyro-technic devices are easily installed at the arming tower through these same doors.

SIX-SEGMENT HINGED HEAT SHIELD

Concept 5260-5 (Figure 18) utilizes segments of the shield structure as landing skids. When the segment is rotated down about the hinge line, the toroidal section of the heat shield becomes the impact area of the segment. The double curvature of the toroid provides a shoe footprint similar to that of a LEM type pad. Six hinged panels were chosen to minimize the possibility of the edges of the segments digging into earth or water, thereby reducing undesirable overturn or yaw destablizing moments. Each segment is hinged from the inner edge at two places, and a single vertical strut is provided for deployment and landing impact attenuation.

The segment has a vertical deflection of 12 inches for vertical only descent vector and a 32.75 arc travel for combined vertical/lateral vectors. Landing vectors in the effective structural plane will produce large structural forces if the 'g' onset rate of the main vertical shock absorber is high. Also, in-plane force vectors causing C/M yaw will produce high structural forces. Basically, the hinged heat shield can absorb energy about the hingeline, but cannot absorb energy in-plane of the hinge-effective structural plane.

System Physical Description

Six segments of the heat shield are structurally isolated from the main heat shield and hinged on an axis that is normal to a 40 inch radius. The segment is a solid panel approximately 35 inches wide and 18 inches radial length from the 75.750 moldline radius. Extended inboard from the panel portion are two structural arms of approximately 4.50 inches in width, 20 inches in length and 2.50 inches thick. At the pivot end of each leg is a 4.5 inch piano hinge. 1 The radius of curvature of the heat shield permits both legs to have a common hinge line. To the C/M inner body at coordinates X_C = 40.134 and R_C = 61.890 is attached a pyro-technically pressurized liquid/gas spring damped with a fluid orfice piston. The unit is a double extension two slope energy absorber. The moving end is attached to the heat shield segment at coordinates X_C = 16.000 and R_C = 68.000 with a spherical Dyflon type bearing. The segment/strut attach fitting distributes the strut loads over a relatively large area of the initial footprint of the segment.

Integration of the segment deployment and attenuation strut into the aft equipment bay does not permit a diametrically opposed pair of segments to be in the Z-Z axis of the C/M although this is the plane of maximum horizontal touchdown velocity. The location of the RCS pitch and yaw engine clusters in the Z and Y planes require that the plane of the hinged segment be displaced from the principal axes by 17°.
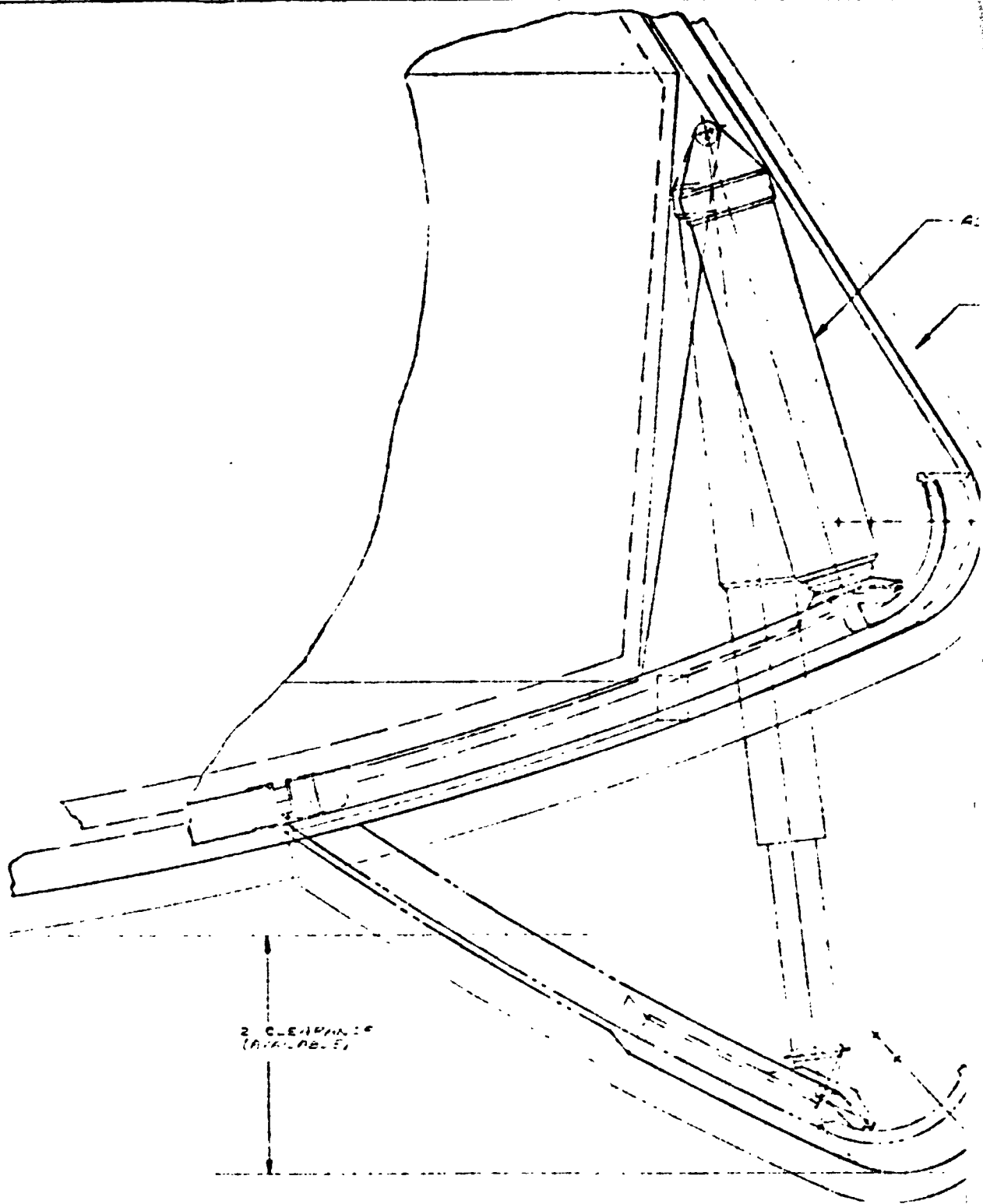
SECTION D-D ROTATED 17°14'-43.75'
SCALE - 1/4 SIZE

2 CLEARANCE
(AVAILABLE)

ACTUATOR/SHOCK ABSORBER

-ABLATOR ML (REF.)

HELIUM TANK
(REPOSITIONED)

¢ PAD NO. 4
θ₁ = 222°-45'-11.25"

RCS PITCH ENGINES

32.75 STROKE AFC
(AVAILABLE)

TENSION TIE NO. 3
θ₁ = 292°-45'-11.25"

¢ PAD NO. 6
θ₁ = 332°-45'-11.25"

35° (TYP)

VIEW LOOKII
SCALE - 1/10 ...

2

RCS YAW ENGINES

TENSION TIE NO. 2
Θ=152°-45°-17.25°

RCS FUEL TANK (REPOSITIONED)

RCS FUEL TANK

ACTUATOR/SHOCK ABSORBER

LANDING LEG (HEAT SHIELD PANEL)

POTABLE WATER TANK
(REPOSITIONED)

WASTE WATER TANK

(PAD.NO. 2
Θ=102°-45°-17.25°

+Z

RCS OXIDIZER TANK

RCS OXIDIZER TANK
(REPOSITIONED)

TENSION TIE NO. 1
Θ=42°-45°-17.25°

HELIUM TANK

RCS YAW ENGINES

AFT

3

—GROUND LINE

DEPLOYED CONFIGURATION AT TOUCHDOWN

FIGURE 18

SCALE	DR. D R A W N	
NOTED	DATE 15 APR '63	◆ NORTH AMERICAN AVIATION INC
	MODEL	

SIX SEGMENTS HINGED -
HINGED HEATSHIELD CONCEPT,
M-SOAS STUDY

52C.O-5

On signal to deploy the landing impact segments a pyro-technic gas
supply is fired and pressure is felt in the strut gas chamber and in the
liquid spring oil reservoir. The fully compressed struts initial motion
fractures the strut welded seal and the ablator fusions line along the
segment to heat shield interface. The oil flow rate orfices damp the
deployment velocity of the segment to the same values required by the land-
ing impact. The time for system deployment will probably be in the order of
from 0.10 to 0.250 seconds. (Values depend on earth/water impact require-
ments.) For best results, the C/M should hang coincident to the local
gravity vertical.

Spacecraft Compatibility

The C/M inner body structure, heat shield structure and systems instal-
lation in the aft compartment will require a major redesign. The concept
can be installed in available space, however. One of the RCS helium spheres,
oxidizer tank and fuel tanks must be repositioned, in addition to the portable
water tanks. The remaining tanks can remain unaffected positionally. Main
external longerons will have to be added to aft side wall of the inner
pressure shell to provide a load distribution and attachment for the six
attenuation struts.

Functional Considerations

This system, like the four-legged gear and the four-segment translated
heat shields, requires joints and discontinuities in the aft heat shield and
uses pyro-technic devices to deploy the heat shield segments. The deployed
segments are supported at the actuator/attenuator strut and at the hinge to
the heat shield; therefore the need for modification to the Apollo inner
structure is minimized. As with all concepts which use deployed heat shields,
dual pyro-technic cartridges and circuits will be installed to enhance system
reliability.

DEPLOYED HEAT SHIELD/AIR BAG

Concept 5260-6 (Figure 19) employs an extended aft heat shield, suspension
angle of zero degrees, and impact attenuation by means of an airbag and
between the inner structure and heat shield. This concept does not change the
equipment arrangement in the aft compartment in any way. However, some
structural changes are necessary. Energy in the vertical direction is dissi-
pated by exhausting trapped air through orifices and horizontal energy is
dissipated by sliding friction over the ground.

System Physical Description

The hardware consists of a series of gas operated separation nuts which
take the place of existing heat shield attachment bolts, a cylindrical non-
porous fabric cylinder equipped with one-way air inlet ports and blow out
diaphragms. This cylinder is attached to the inner structure and the heat

-33-

SID 65-1205

shield. In addition, a series of cross brace cables are installed around the perimeter of the bag to limit the horizontal movement of the heat shield relative to the command module during skid out.

In operation the separation nuts on the heat shield attachment studs are energized by a common source pyro-technic gas supply. The nuts are designed to stroke the heat shield downward. As the heat shield extends, the volume formed by the inner and outer heat shield and the cylindrical fabric wall fills with air through ports covered with one-way flap valves. Heat shield extension is limited by the wire braces. On impact, the compressed air escapes through orifices after burst diaphragm pressure is reached and as landing energy is absorbed. The concept shown has a heat shield extension of 10", although this value could be increased within reasonable limits if considered necessary.

Spacecraft Compatibility

Structure in the lower part of the spacecraft will require minor modification to install this concept. Changes are mainly the addition of circular rings for mounting the separation nuts and wire cable braces. In the forward equipment bay, however, modifications are required to change the suspension angle to zero degrees. This concept does not change the equipment location in the aft compartment. Insulation between the inner and outer heat shield remains essentially unchanged except for a small area in which the air bag is stowed. Temperature to which the bag can be subjected is limited by the fabric material. After reentry, the back face temperature of the heat shield is expected to reach 500°F, which is within the capability of materials such as HT-1. The current structural concept of the tension ties which penetrates the heat shield and attaches to the inner shell external longerons will require revision. The tension ties will have to be cut in the aft equipment bay in order to permit deployment of the heat shield.

Functional Considerations

Heat shield deployment is performed by a series of gas operated separation nuts. These nuts are energized by a common pyro-technic gas supply from dual cartridges. This system will exhibit good reliability for the deployment sequence but it is important to design adequate safety features into the system to prevent inadvertant activation. Functionally, the system could achieve the same reliability as the airbag system used on the Mercury spacecraft.

TRICYCLE LANDING GEAR

Concept 5260-7 (Figure 20) features a conventional tricycle landing gear consisting of two main gears deployed from the aft equipment bay and a nose gear equipped with skids which is deployed from the forward recovery gear compartment. The prime advantage of this concept lies in the standard orientation of the flight crew and their ability to see that ground directly out of the docking window. All the other concepts presented must employ

PERIPHERAL WIRE ROPE BRACES

SEPARATION NUTS
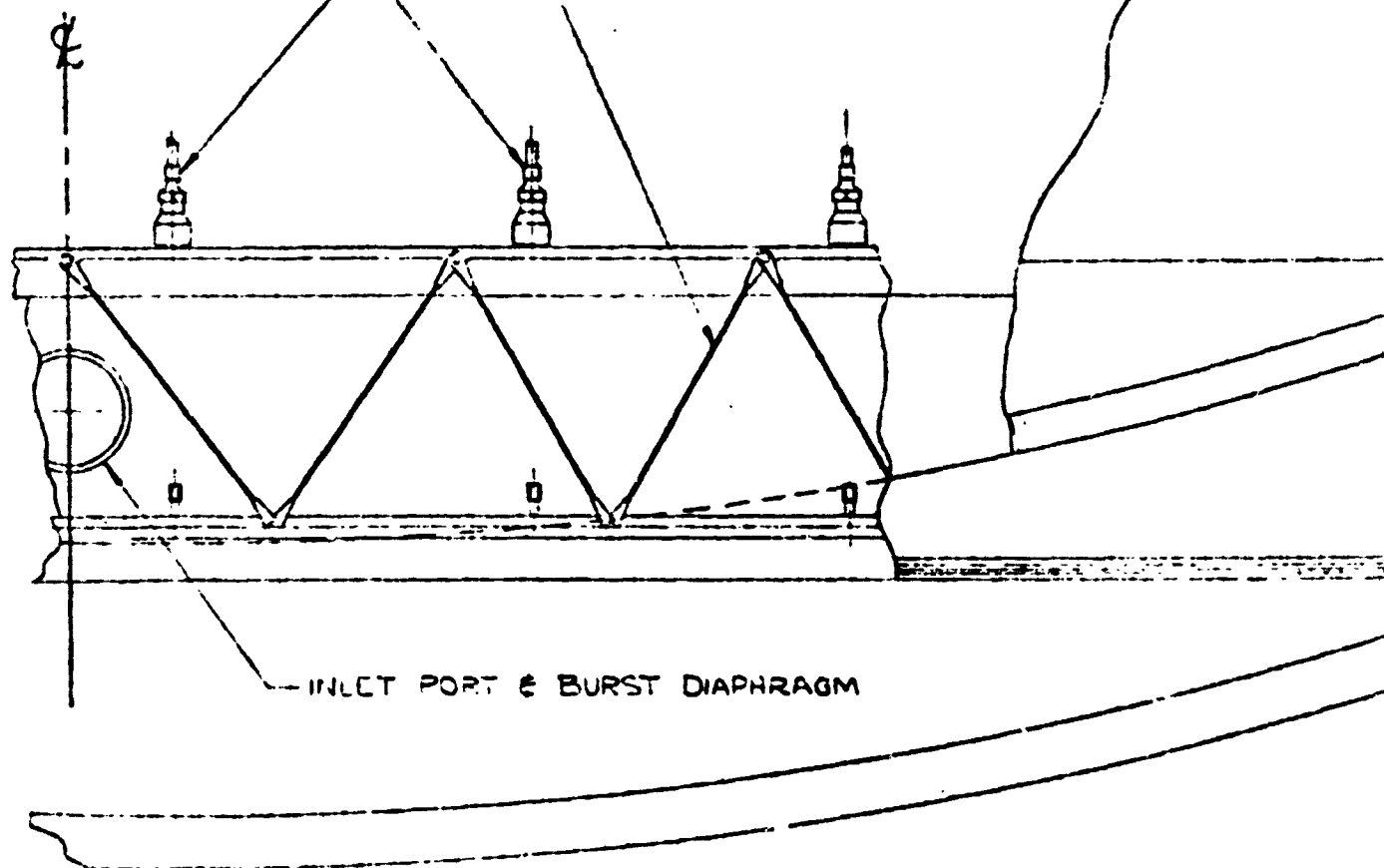
INLET PORT & BURST DIAPHRAGM

DETAIL SHOWN
DEPLOYED

PRESSURE WALL —

STOWED AIR BAG —

MICRO-QUARTZ INSULATION —

10.0

— TEXTILE BAG DEPLOYED

— HEAT SHIELD

TYPICAL S:
EQUIPMENT

NO HEAT SHIELD
SCALE ½

2

$X_C \cdot 23.2$

SEPARATION NUT

THRUST RING

INSULATION
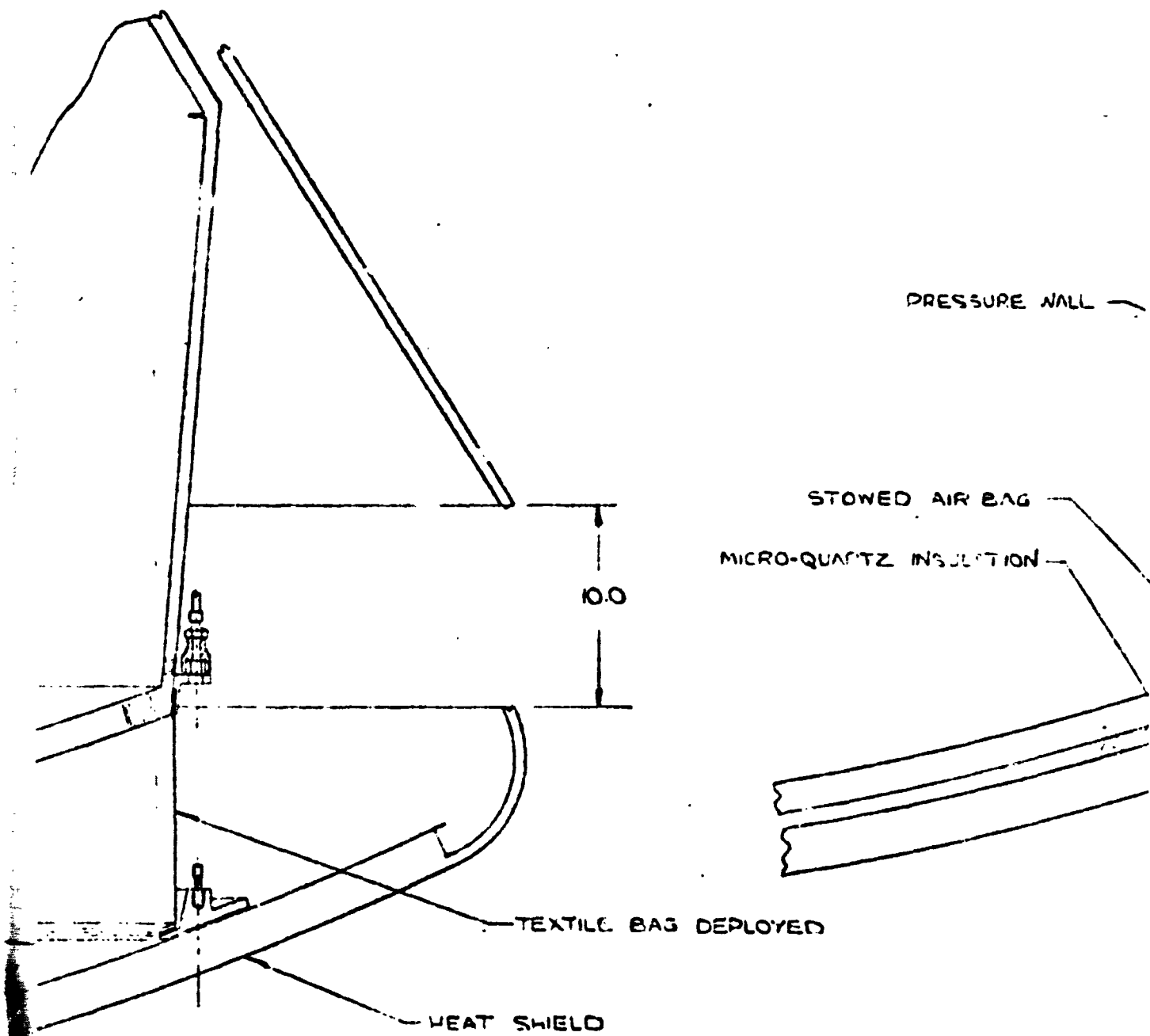
HEAT SHIELD
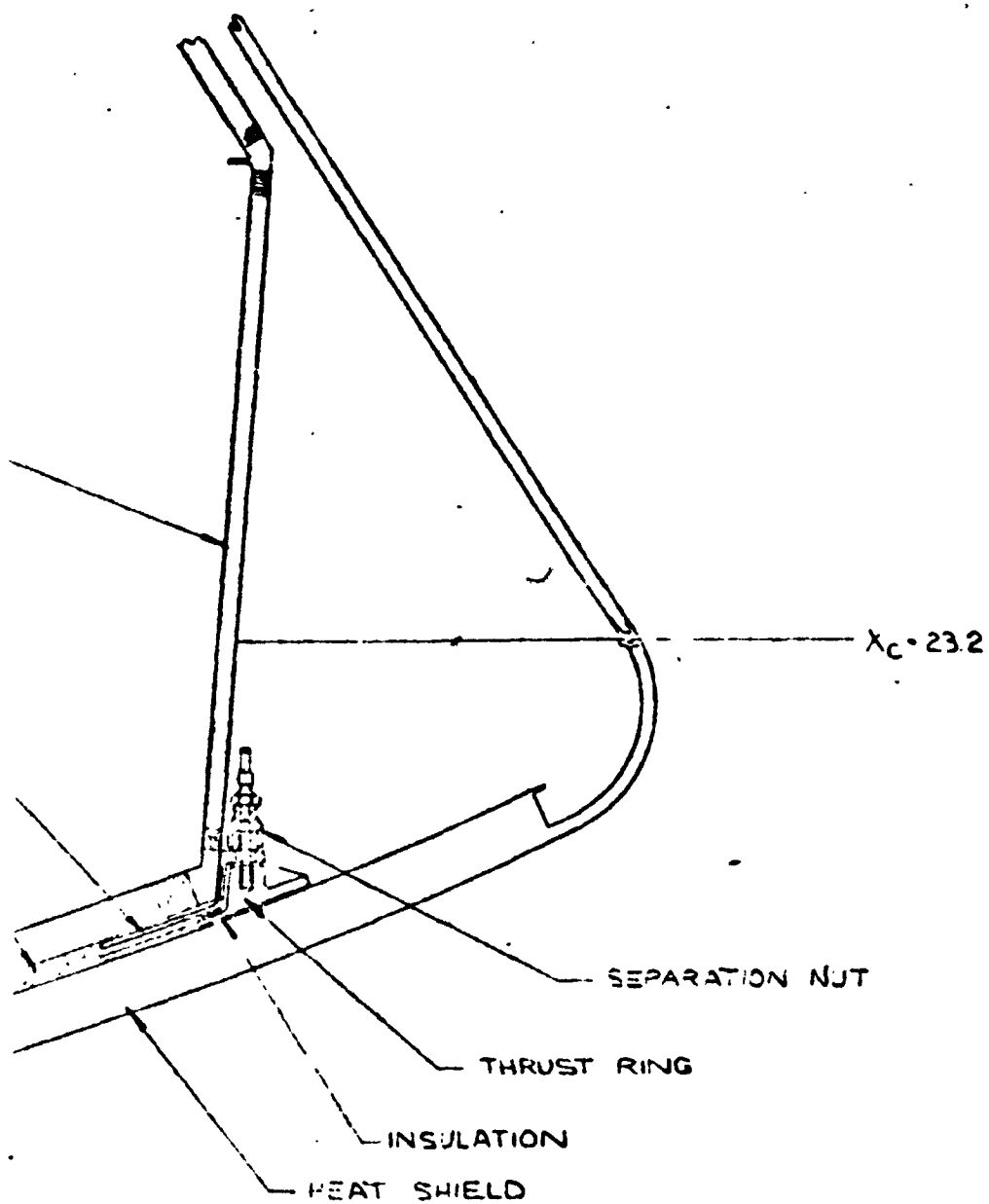
:CTION OF AFT
COMPARTMENT
SCALE ¼

3

DEPLOYED CCN

GROUND LINE
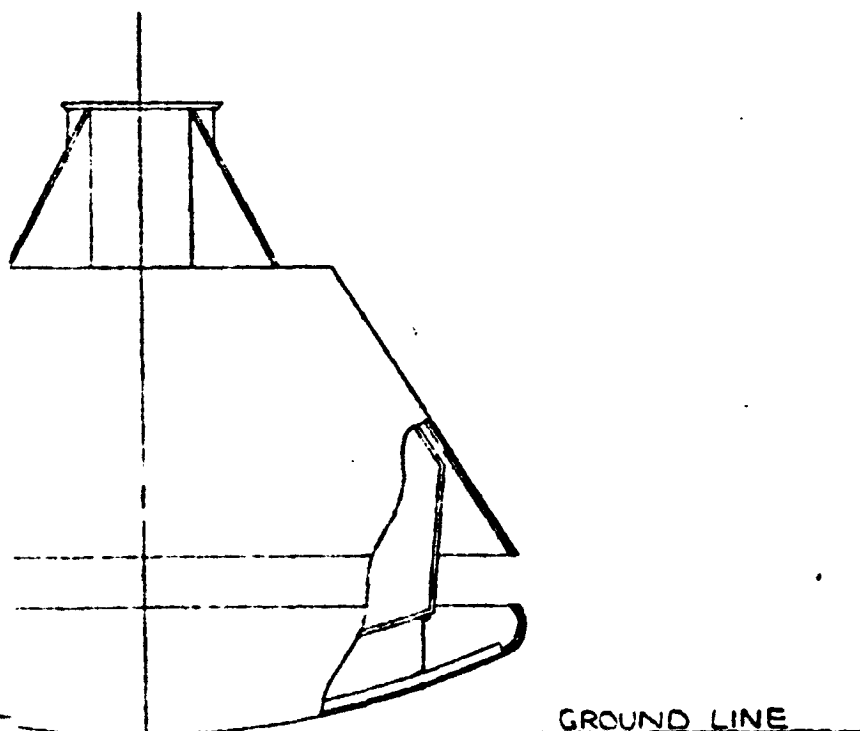
!FIGURATION AT TOUCHDOWN

NOTE :
    THIS CONCEPT DOES NOT REQUIRE
    ANY PELICATION OF MAJOR EQUIPMENT
    COMPONENTS IN THE AFT EQUIPMENT BAY

FIGURE 19

SCALE				
½₀		NORTH AMERICAN AVIATION, INC		
		EXTENDED HEAT SHIELD AIRBAG CONCEPT MISDAS STUDY		52.60-6

145

B

A
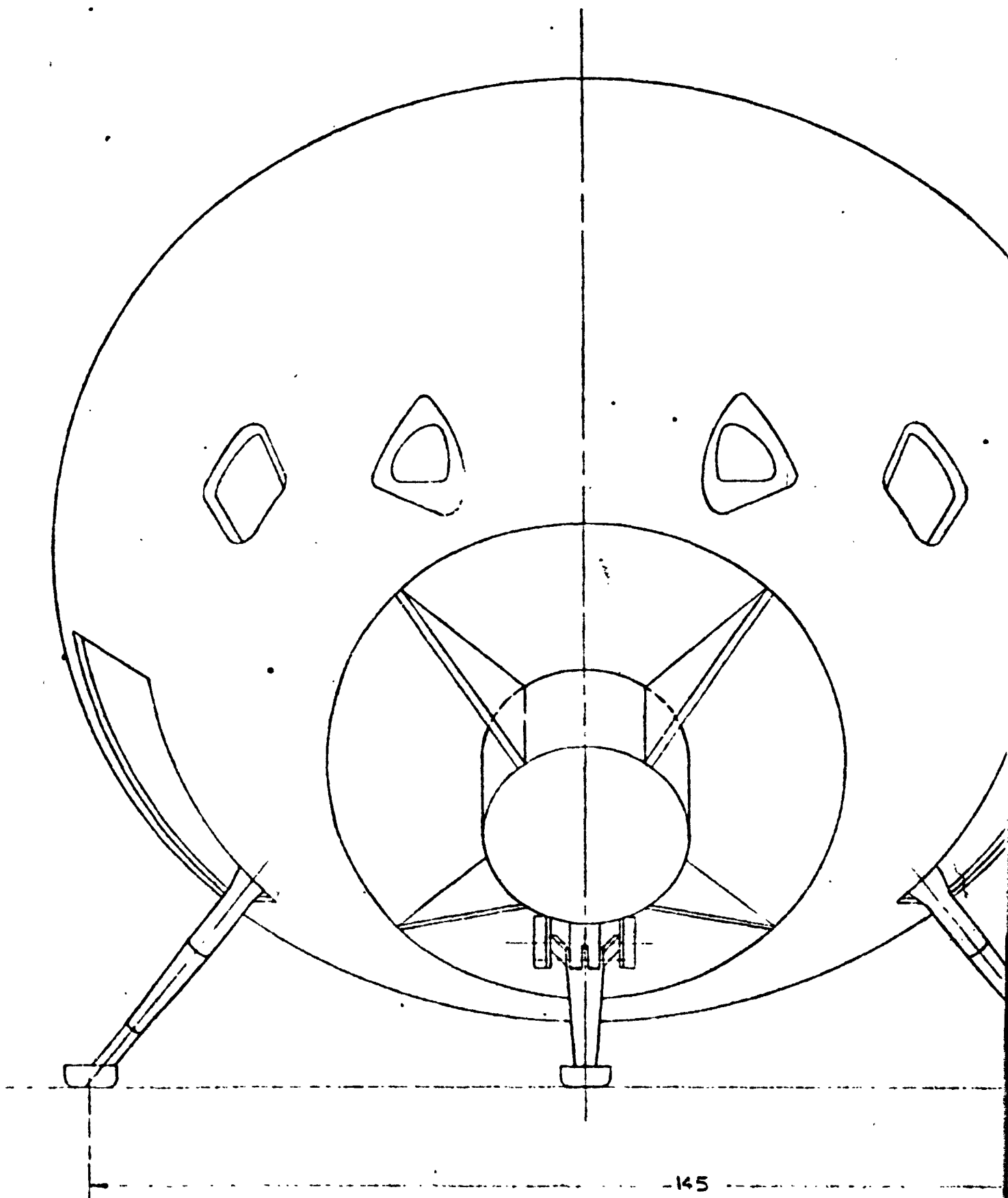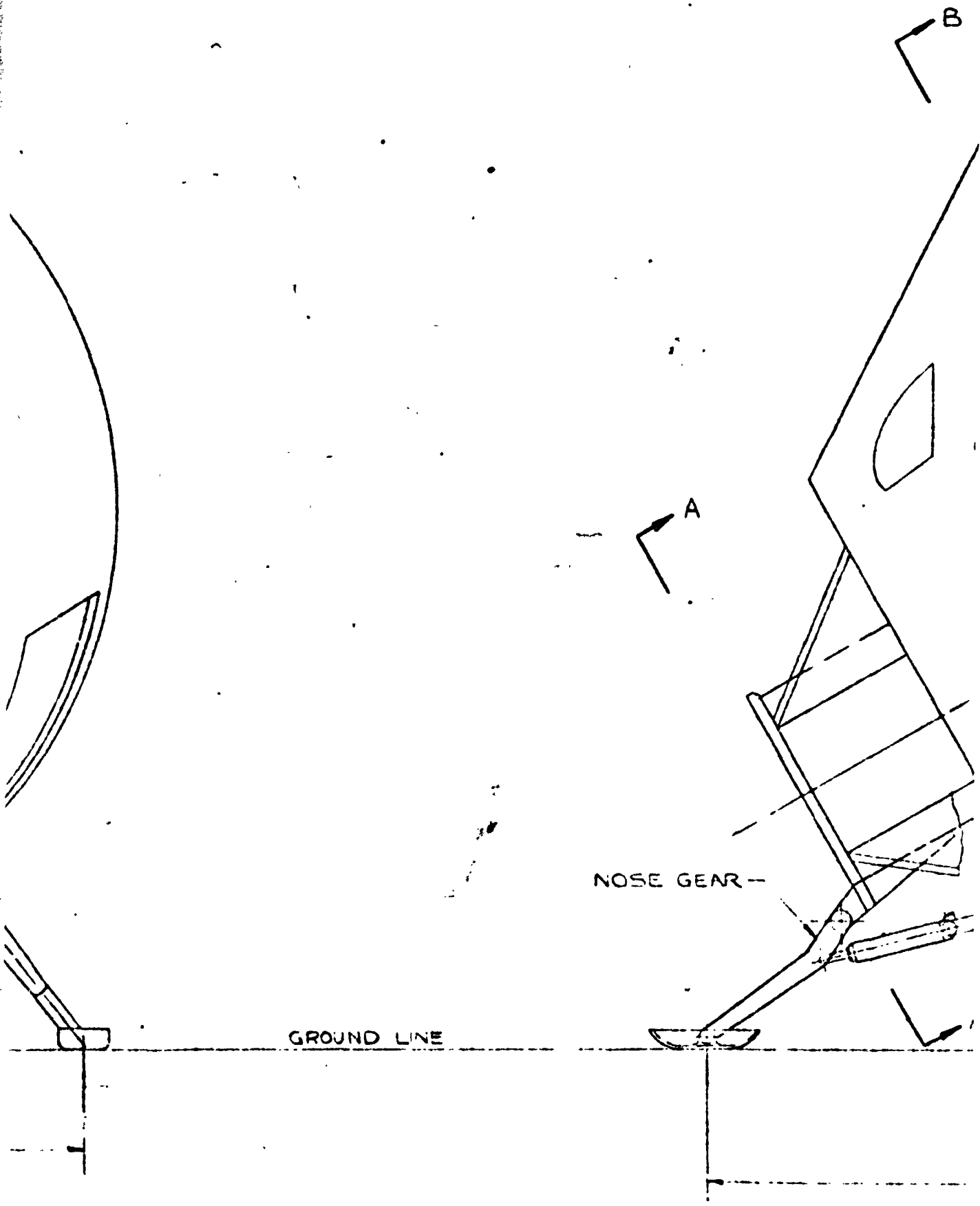
NOSE GEAR—

GROUND LINE

2

30°

LON.

MAIN PARACH

66.5

MAIN GEAR

A

28.5

107

B

3

RCS PITCH MOTORS

PARACHUTE

-Z

LONG NO.3

MAIN PARACHUTE

-Y

RCS ROLL MOTO

NO.4

LONG NO.2

JTE

+Y

HELIUM TANK
(REPOSITIONED)

LONG NO.1

+Z
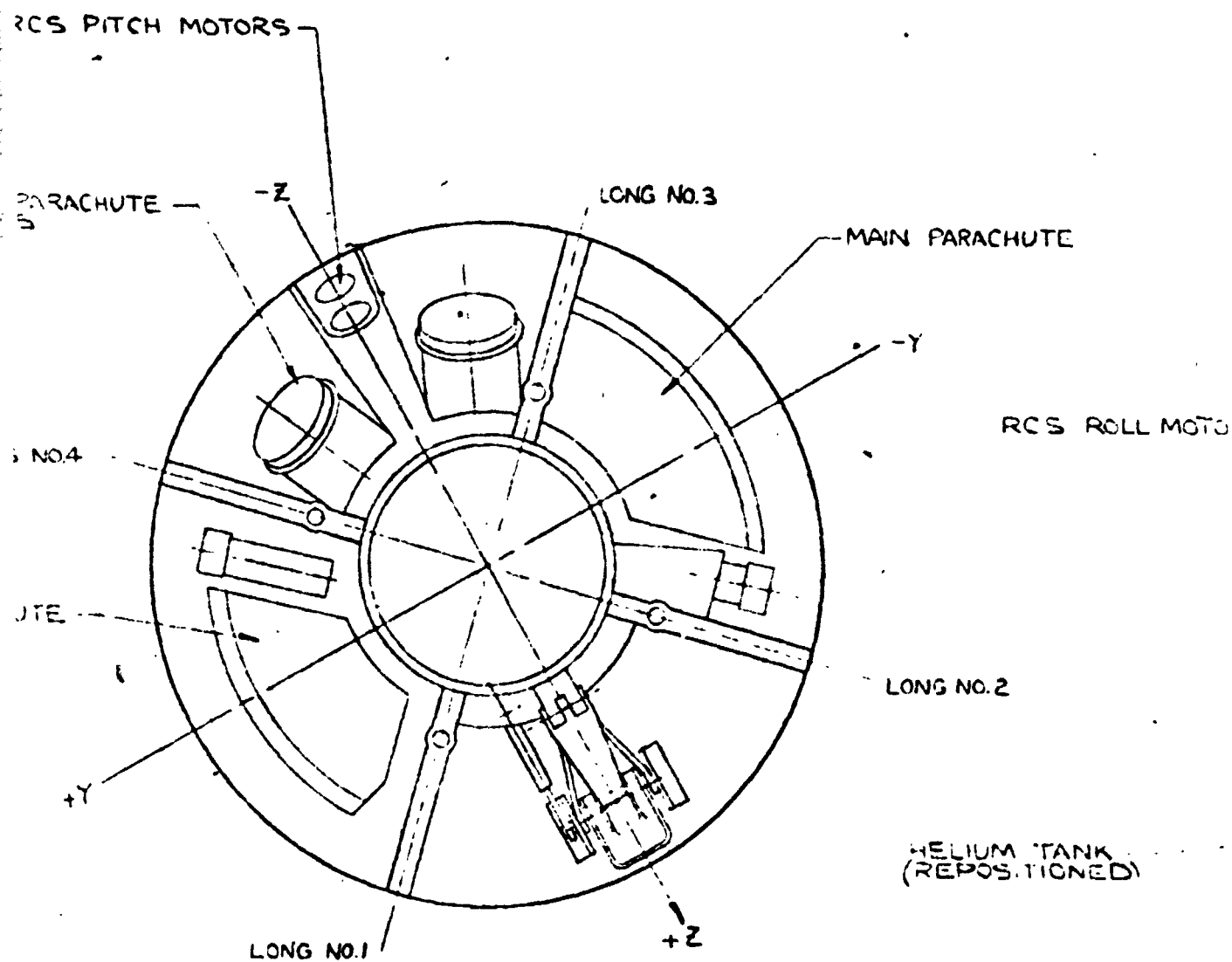
VIEW ON A-A
(NOSE GEAR IN STOWED POSITION)

EJECTA
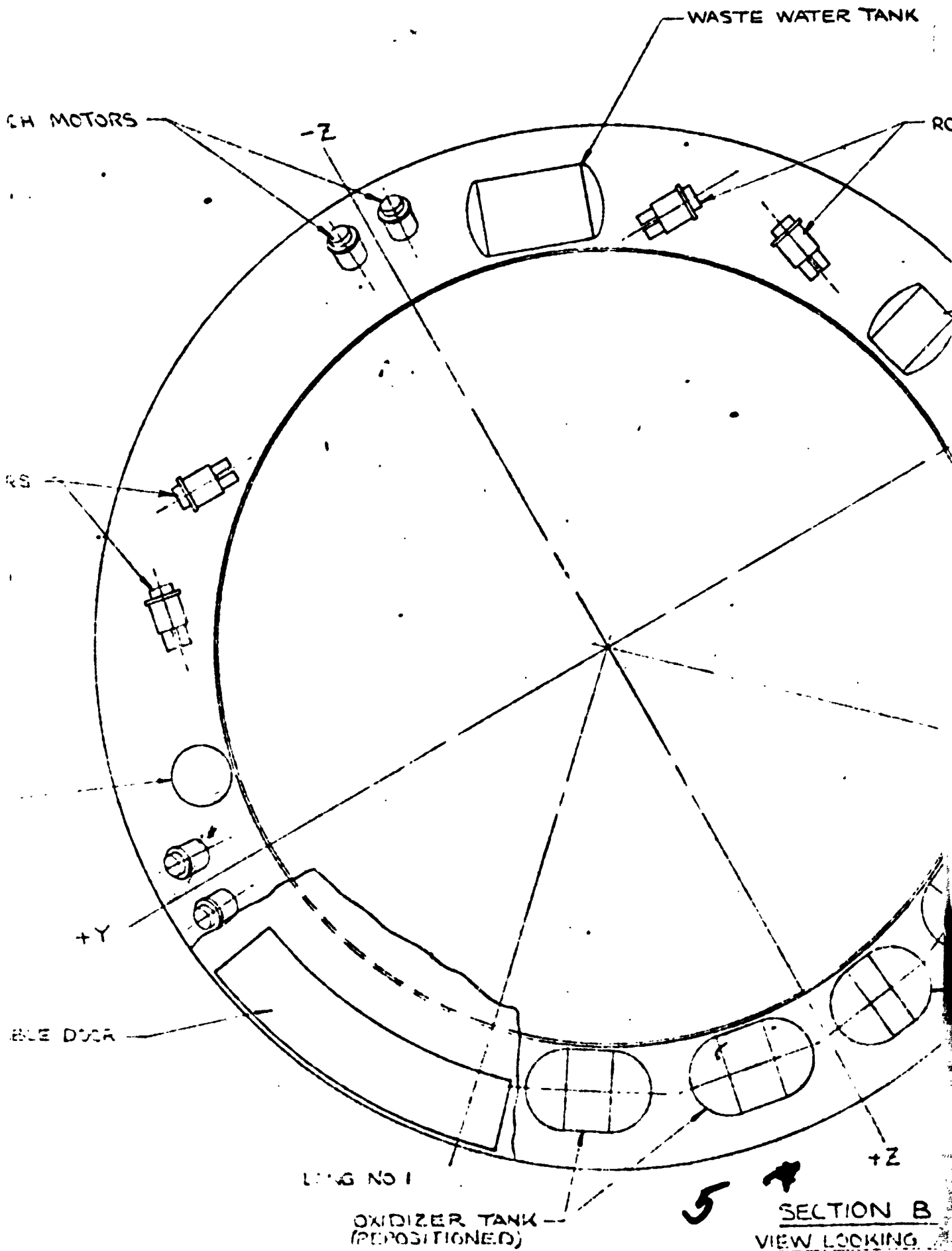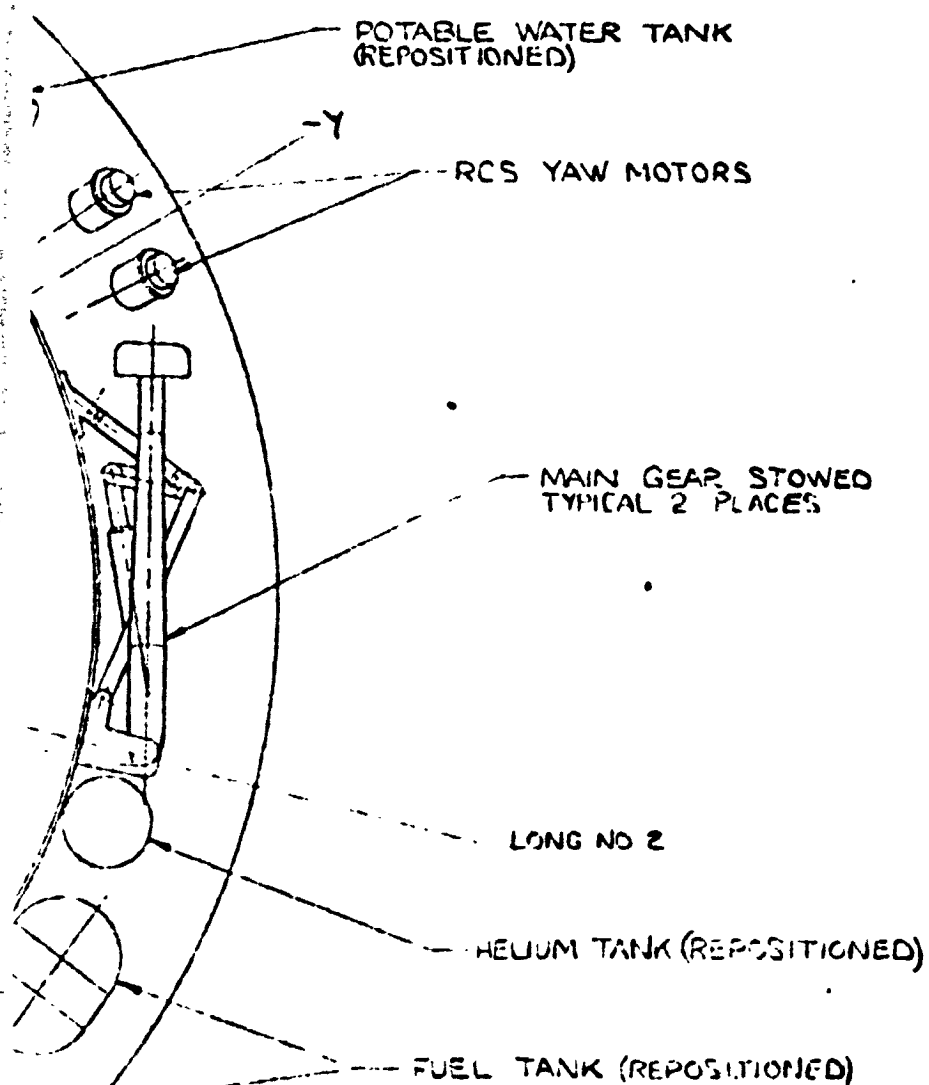
WASTE WATER TANK

CH MOTORS

−Z

RC

RS

+Y

BLE DOOR

LING NO 1

OXIDIZER TANK
(REPOSITIONED)

5

+Z

SECTION B
VIEW LOOKING

S ROLL MOTORS

POTABLE WATER TANK
(REPOSITIONED)

-Y

RCS YAW MOTORS

MAIN GEAR STOWED
TYPICAL 2 PLACES

LONG NO 2

HELIUM TANK (REPOSITIONED)

FUEL TANK (REPOSITIONED)

THIS PRINT REDUCED
HALF
SIZE

FIGURE 20

TRICYCLE LANDING GEAR
CONCEPT MISDAS STUDY

-B
AFT

6

5260-7

— 37,38 —

S1060 1205

some method of providing a view of the ground by indirect means (such as television) while the crew flys lying on their backs. However, to achieve these advantages, the desired suspension angle of 27° has been changed.

It has been shown in the past that to maintain yaw stability in the direction of travel, the friction force developed by the trailing shoes must be greater than the shoe forward of the c.g. One method of achieving this criteria is to design the shoe surfaces to develop the required coefficient of friction, however, the method chosen is to land in a nose up attitude so that at initial contact the trailing shoes only are in ground contact.

System Physical Description

The nose gear is stowed in the lower quadrant of the parachute compartment and is extended after main recovery system deployment. The skid has a vertical travel of 16 inches working against an oleo strut. Gear extension is accomplished by means of a cartridge activated thruster. The two main gears are located in the aft equipment bay and also employs oleos for energy absorption and cartridge activated thrusters for extension. In addition, an ejectable door is required for each main gear, employing pyro-technic devices for separation. Ten inches of vertical stroke in the plane of the skids is provided in this configuration.

Spacecraft Compatibility

The tricycle landing gear is compatible with the spacecraft only after considerable spacecraft modification. The nose gear is installed in a sector presently occupied by a recovery parachute. However, a recovery system which utilizes a gliding parachute would probably employ only two parachutes. A general strengthening of the docking hatch area is required for nose wheel loads. Rearrangement of the equipment in the aft equipment compartment is required for stowage of the main gear and is shown as the concept drawing. At the same time, the doors which allow access to this equipment must be suitably relocated. The main gear jettisonable doors will provide satisfactory access to the gear components.

Installation of this system in the spacecraft will require a modification to the recovery system sequence controller to provide a signal for beginning of landing gear extension. In addition, gear-downlock indication lights will be required on the display panel.

System Functional Considerations

Premature operation of the landing gear is considered an extremely remote probability. The reliability of the system including nose gear door jettison and gear extension is as good as tower jettison and forward heat shield release. Therefore, the concept should be compatible with crew safety and reliability criteria.

Dual pyro-technics will be employed to enhance reliability of the system. Servicing and installation of cartridges may be performed easily at the arming tower by removing the main gear door and the forward heat shield. At this time all system compartments are readily accessible. Refurbishment of the landing system consists of replacing the energy absorbing devices in each leg and replacing the skids.
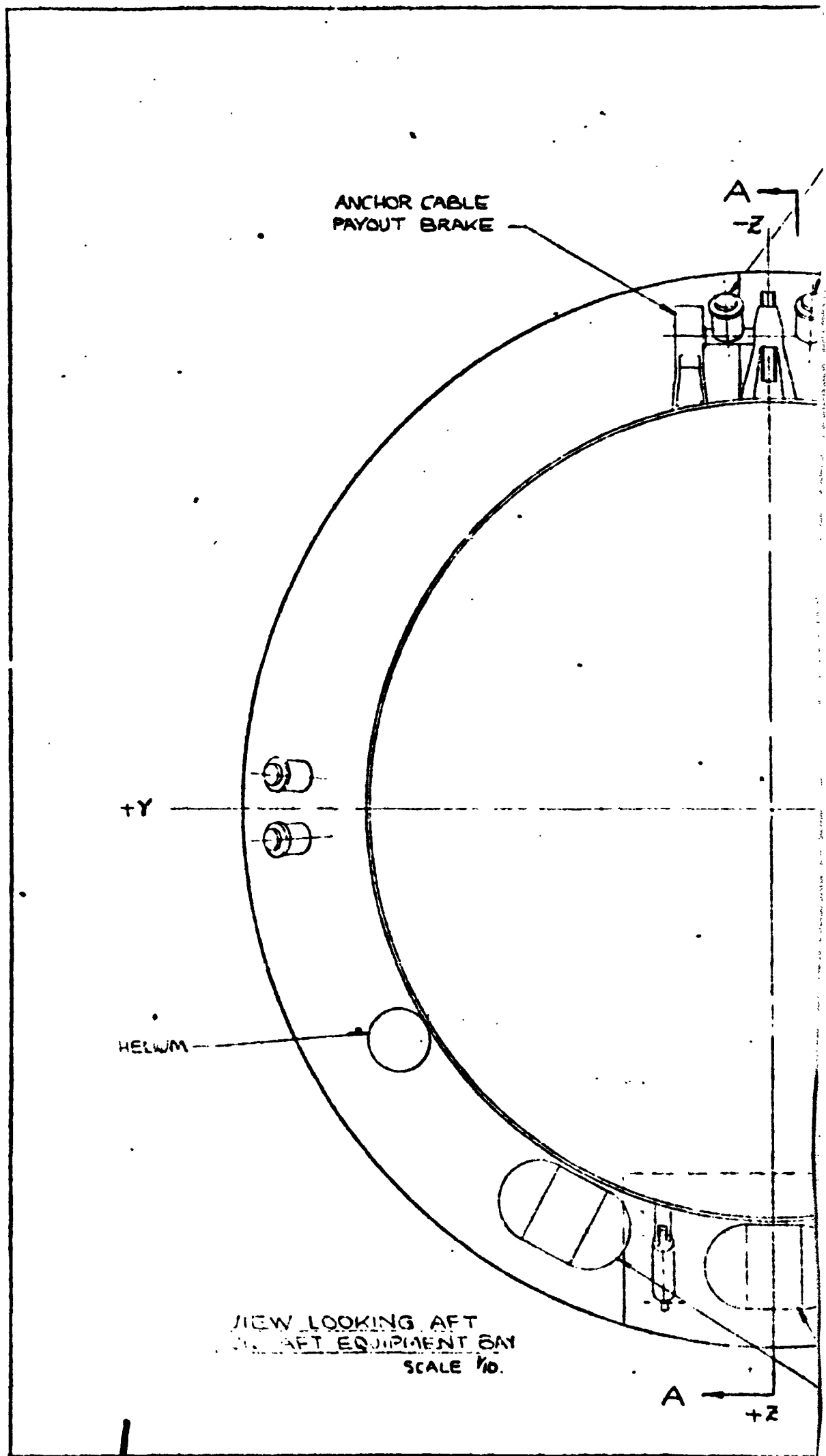
IMPLANTED ANCHOR

Concept 5260-8 (Figure 21) employs a small skid located in the forward edge of the heat shield and a ground-implanted anchor and anchor cable to prevent tumbling. The vertical landing impact is attenuated by closing the skid while energy is dissipated by two liquid springs located between the skid and the inner body. Horizontal energy is dissipated by frictional forces developed between the skid and ground. The force developed in the anchor cable is designed to resist the tumbling moment only, and since the moment arm between the friction force on the ground and the force in the cable are approximately equal, the load in the cable for conceptual design purposes may be assumed to equal the horizontal frictional force on the ground. For instance, at first impact the vertical load is assumed to be three times the vehicle weight. Thus, the maximum anchor cable load, assuming a coefficient of friction of 0.5, will be 21,000 lb. However, in actual practice, the force required will be somewhat lower due to the effect of vehicle inertia and the inherent vehicle stability. During steady state skid-out, the cable force is expected to be about 10,000 lbs. Although the prime reason for having the anchor is to prevent tumbling in the direction of travel, other benefits, documented in the following paragraph are apparent.

Unlike other concepts where a yawed landing will spin the vehicle because the ground contact occurs in front of the c.g., this concept automatically aligns the vehicle in the direction of travel. In addition, the desirable suspension angle of 27° is maintained.

System Physical Description

The hardware consists of a skid formed by hinging a 44" wide sector a distance of 10" downward. This is accomplished by gas-operated thrusters which also duplicate as attenuators of the return stroke. The area around the -Z axis RCS motors contains the anchor assembly mortar, cable storage drum with 40 feet of nylon webbing, and friction brake. These units are covered prior to operation by a removable portion of the heat shield.

After main parachute deployment, the skid is deployed downward by a pyro-technic gas supply to the thrusters/attenuators. At the same time the cover over the anchor assembly is ejected. At a predetermined altitude above the ground, probably near the start of retrofire, the anchor and barrel is mortared vertically downward. At the relatively low muzzle velocity the anchor cable, which is attached to the barrel, is extracted from its storage. At ground contact the anchor projectile is fired into

ANCHOR CABLE
PAYOUT BRAKE

A
-Z

A

+Y

HELIUM

VIEW LOOKING AFT
AFT EQUIPMENT BAY
SCALE 1/10.

A

+Z

RCS PITCH MOTORS
(⊄ SPACING INCREASED)

GROUND ANCHOR MORTAR

JETTISONABLE COVER
FOR ANCHOR DEPLOYMENT

CABLE FAIRLEAD

CABLE DRUI

POTABLE WATER TANK

RCS YAW MOTORS

—Y

HELIUM (REPOSITIONED)

SKID DOWN-THRUSTER
AND ATTENUATOR

FUEL TANK
(REPOSITIONED)

WATER TANK (REPOSITIONED)

SKID ENVELOPE

OXIDIZER TANK (REPOSITIONED)

SECTION A - A

2

ANCHOR CABLE

MORTAR ASSY

ANCHOR PROJECTILE

BARREL

CABLE DRUM AND
MORTAR EJECTABLE COVER

DETAIL OF ANCHOR MORTAR
(SHOWN IN STOWED POSITION
C/M AT 27° SUSPENSION ANGLE
SCALE ¼

SKID HINGE LINE

SKID EXTENDED

NO EXTENSION

3

27°

GROUND LINE

SKID

34

ANCHOR CABLE

IMPLANTED ANCHOR

FIGURE 21

5

SCALE		NORTH AMERICAN AVIATION, INC.	

IMPLANTED ANCHOR CONCEPT
MISOAS STUDY | 5260-8

the ground carrying two wire ropes with it. To obviate recoil of the barrel it is anticipated that the principle of the recoiless rifle will be employed. Having entered the ground, the anchor projectile is expanded increasing its pull-out force. In a detailed study of this concept, particular attention would be given to the anchor assembly, because the successful operation of the concept depends on the feasibility of the anchoring system.

As the horizontal movement of the vehicles begin to produce an over-turning moment, tension in the cable provides an opposing moment. Tension is produced in the cable as it unwinds from the storage drum by a friction brake. The force-time history required from the brake would be calculated for the worst combinat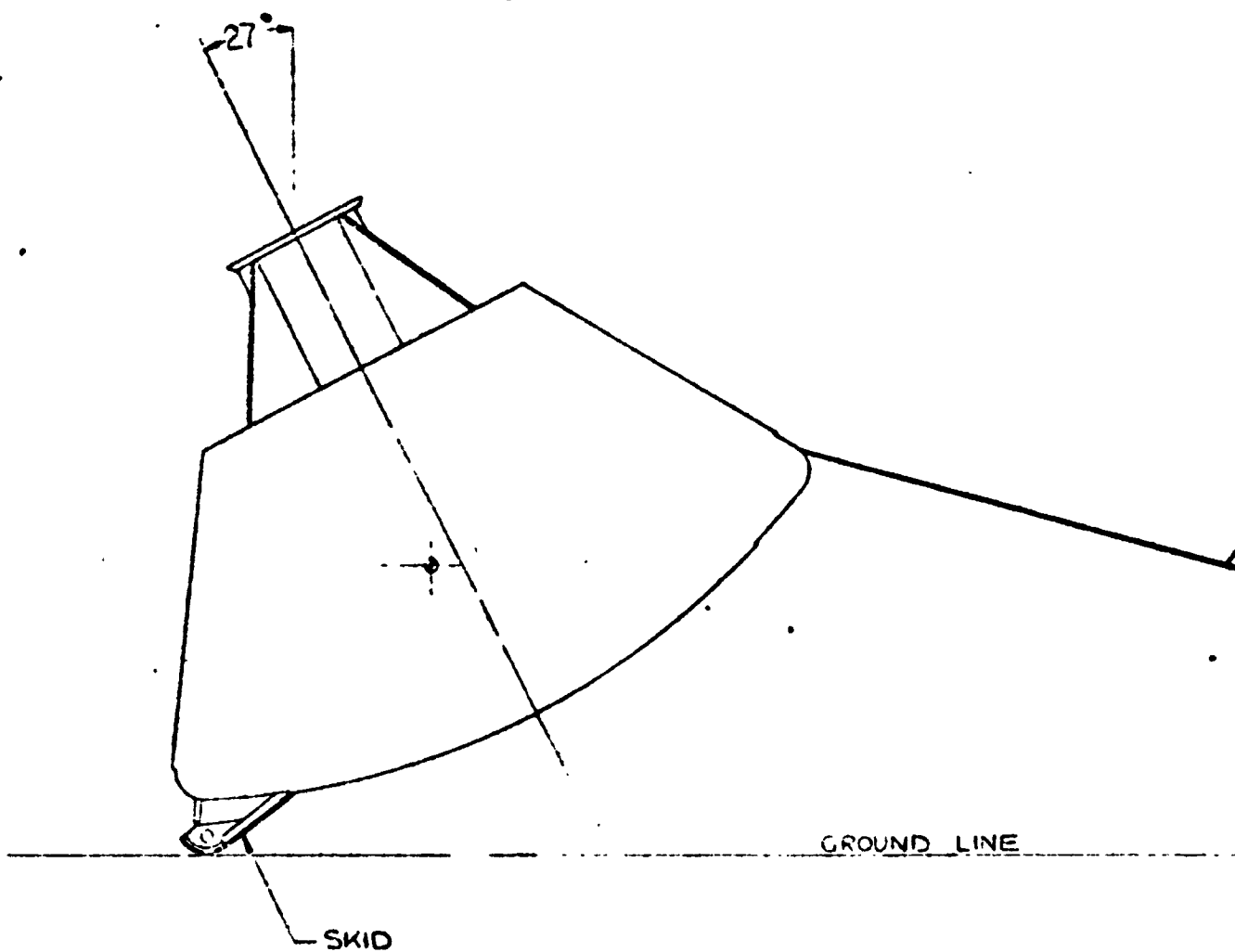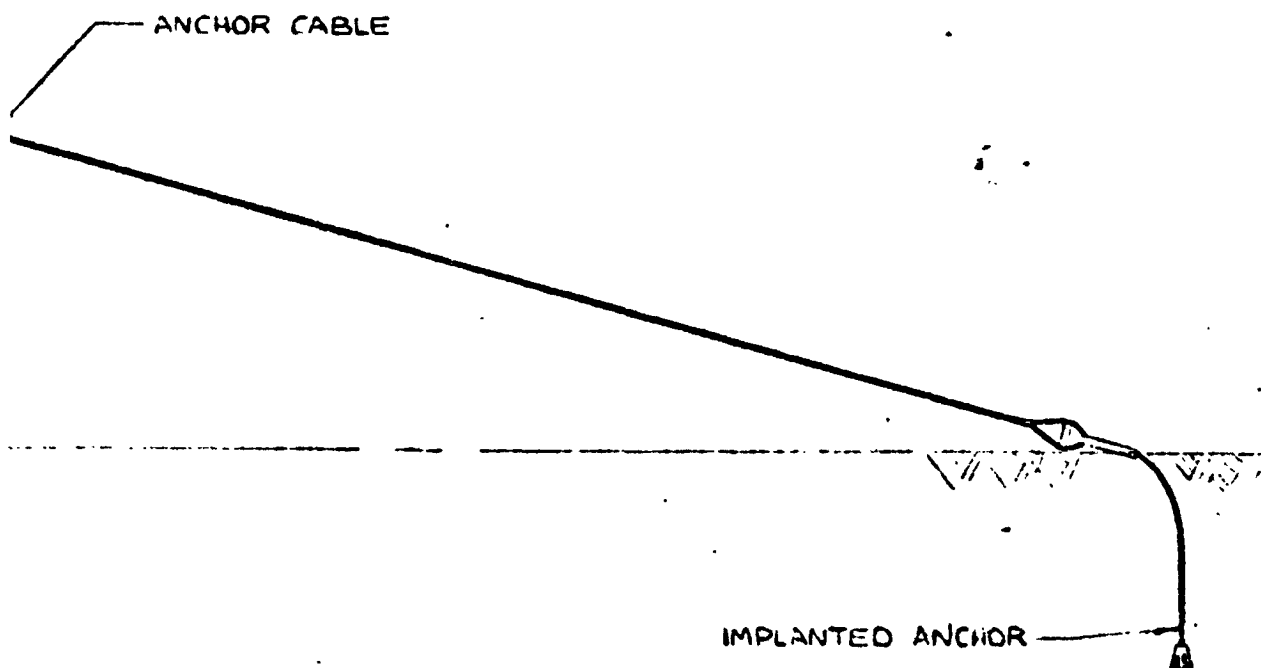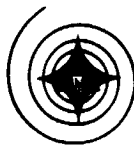ion of conditions. Then, in any other condition the restoring moment will be greater than the overturning moment and the vehicle would tend to fall back on its heat shield.

Spacecraft Compatibility

This concept can be integrated into the spacecraft with a minumum of modification. In common with other concepts, the vertical attenuators require extra stiffeners on the internal pressure shell, together with the elimination of the honeycomb attenuation blocks. In addition, a minor relocation of the RCS oxidizer tanks is required. The area around the -Z portion of the aft equipment bay is relatively free of equipment allowing easy installation of anchor assembly, storage drum and brake. Additional stiffeners will be required for anchor cable loads. A slight change in the spacing of the -Z RCS pitch motors is required to allow installation of the cable storage drum on the center line of the vehicle. The proximity of the main umbilical major wire runs to the area in which the reel system is located may present some space allocation problems.

System Functional Considerations

In essence, the concept is simple, has few moving parts, and requires no complication at the parachute attachment for suspension angle change. Reliability of pyro-technic devices is a proven field. However, reliable operation of the ground anchor is questionable at this time. The feasibility of the anchor would have to be demonstrated for a wide variety of ground conditions from soft mud, through dry sand to solid rock. The reliability of the system may be enhanced at the sacrifice of weight by dual anchor systems. In addition, careful attention to detail will eliminate anchor cable abrasion, contact with hot ablator, etc., as a source of unreliability.

PRELIMINARY STABILITY EVALUATION

The preliminary dynamic studies were concerned with landing stability, i.e. the ability to land and stop on the intended contact points without overturning and impacting other parts of the capsule. When an impact attenuation load was needed for the dynamic analysis, a maximum load of 12 g's constant plastic force was used. In the four-segment concepts, each segment stroked at 3 g's; in the tricycle gear concept, each leg stroked at 4 g's etc.

The stability envelope for each case is defined in terms of the significant variables. In some cases, however, the stability extended outside of the limits of the landing parameters, so no charts are presented. In other cases the stability was obviously unacceptable, so no results are included.

ANALYSIS OF DEPLOYED HEAT SHIELDS WITH EXTENDED SKIDS

Methods and Assumptions

The preliminary analysis of concepts 5260-1 and 5260-2, both of which utilize skids deployed outward from the heat shield to prevent turnover, was based on the following assumptions:

1. Capsule and skid are rigid.

2. Ground is indeformable plane with constant coefficient of friction.

3. Heat shield and skids lie on the arc of a circle.

4. Normal velocity vanishes at point of contact with subsequent vehicle motion in contact with ground.

The first step in the process is to compute the changes in linear and angular momentum of the vehicle during initial impact. This computation is accomplished subject to the constraint that normal vehicle velocity vanishes at the point of contact. From the changes in momentum, one computes linear and angular velocities after initial impact. For the second phase of the analysis, the differential equations of motion are solved using initial velocities from the momentum exchange. Real time solutions are obtained using a Runge-Kutta type numerical integration routine. The derivation of the stability equations is given below.

Consider planar motion only: 3 degrees of freedom.

La Grange equations
$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}}\right) - \frac{\partial T}{\partial q} + \frac{\partial V}{\partial q} = Q \qquad (1)$$

If we neglect all elastic, gravity, and potential forces this becomes

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}}\right) - \frac{\partial T}{\partial q} = Q \qquad (2)$$

Integrating from time t to $t + \epsilon$ where ϵ is the time duration of impact

$$\int_t^{t+\epsilon} d\left(\frac{\partial T}{\partial \dot{q}}\right) - \int_t^{t+\epsilon} \frac{\partial T}{\partial q} \, dt = \int_t^{t+\epsilon} Q dt \qquad (3)$$

The first term can be integrated to give

$$\left(\frac{\partial T}{\partial \dot{q}}\right)_{t+\epsilon} - \left(\frac{\partial T}{\partial \dot{q}}\right)_t = \Delta\left(\frac{\partial T}{\partial \dot{q}}\right) \qquad (4)$$

The second term vanishes since it will be assumed that the time duration of impact is infinitesimal while $\frac{\partial T}{\partial q}$ is assumed to remain finite. The right hand side of Equation (3) does not vanish since the impulsive forces during impact can become infinitely large. Hence, the following form will be used:

$$\left| \Delta\left(\frac{\partial T}{\partial \dot{q}}\right) \right| = \left| Q' \right|$$

Using the Apollo axis convention, the following equations result

$$\left.\begin{aligned}
m(\dot{X} + V_N) &= F_N' \\[8pt]
m(\dot{Z} - V_T) &= -\mu F_N' \\[8pt]
I(\dot{\Theta}) &= -F_N(r_G \sin \Theta_o) + \mu F_N(R - r_G \cos \Theta_o) \\[8pt]
-\dot{\Theta} r_G \sin \Theta_o + \dot{X} &= 0
\end{aligned}\right\} \qquad (5)$$

-45-

The last equation represents the geometric constraint at the point of contact; the vertical velocity component at this point must vanish. Eliminating $F_N^!$ and $\dot{X}$ from Equation (5) we have

$$\left| \begin{matrix} \dot{Z} \\ \dot{\Theta} \end{matrix} \right| = \left[[A]^{-1} [B] \right] \left| \begin{matrix} V_N \\ V_T \end{matrix} \right| \qquad (6)$$

where:

$$[A] = \begin{bmatrix} m & , \mu m r_G \sin \theta_o \\ m (R - r_G \cos \theta_o) & , I + m r_G^2 \sin^2 \theta_o \end{bmatrix}$$

$$[B] = \begin{bmatrix} -\mu m & , + m \\ -m r_G \sin \theta_o & , + m (R - r_G \cos \theta_o) \end{bmatrix}$$

As a result of Equation (6), we can solve directly for $\dot{X}$ and F_N'.

$$\left| \begin{matrix} \dot{X} \\ F_N' \end{matrix} \right| = \begin{bmatrix} 0 & , r_G \sin \theta_o \\ 0 & , m r_G \sin \theta_o \end{bmatrix} \left| \begin{matrix} \dot{Z} \\ \dot{\theta} \end{matrix} \right| + \begin{bmatrix} 0 & , 0 \\ m & , 0 \end{bmatrix} \left| \begin{matrix} V_N \\ V_T \end{matrix} \right| \qquad (7)$$
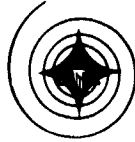
Rearranging and combining with Equation (6) yields

$$
\begin{vmatrix} \dot{Z} \\ \dot{\theta} \\ \dot{X} \\ F'_N \end{vmatrix} = \begin{bmatrix} \begin{bmatrix} [A]^{-1} & [B] \end{bmatrix} \\ \begin{bmatrix} O, & r_G \sin\theta_o \\ O, & mr_G \sin\theta_o \end{bmatrix} \begin{bmatrix} [A]^{-1} & [B] \end{bmatrix} + \begin{bmatrix} O, & O \\ m, & O \end{bmatrix} \end{bmatrix} \begin{vmatrix} V_N \\ V_T \end{vmatrix} \quad (8)
$$

Equation (8) defines the velocities immediately after impact, $\dot{X}$, $\dot{Z}$, $\dot{\theta}$ and the magnitude of the impulse in terms of initial velocities V_N and V_T, friction coefficient, and initial vehicle position at the instant of impact. $\dot{X}$, $\dot{Z}$, and $\dot{\theta}$ will establish the limits for stability, and F'_N establishes the energy-absorbing requirements of the load attenuation system during landing.

Results of Preliminary Analysis

Because of their geometric similarity, one analysis was performed for Concepts 5260-1 (chordwise skids) and 5260-2 (radial skids). For Concept 5260-1, the skids will not stabilize the spacecraft for roll angles of ± 90 degrees; therefore Concept 5260-1 cannot satisfy the stability criteria of this study.

The stability envelope for Concept 5260-2 is defined in Figures 22 and 23. In this case, with radial skids, the problem reduces to one of two dimensions in terms of normal velocity, tangential velocity, capsule attitude, and friction. In all of these overturning cases, the tangential velocity was assumed high enough to maintain a sliding force. This required velocity was 16 F.P.S. or more. It must be noted that the capsule initial attitude angle can be either positive or negative with equal probability due to lack of roll orientation. All overturning cases in this category were caused by an initial impact on one edge of the capsule followed by two or more "rocking" oscillations. The positive attitude angles indicate initial impact on the trailing section. The negative attitude angles indicate initial impact on the leading portion of the heat shield.

ANALYSIS OF CONCEPTS WITH LEGGED GEAR

Methods and Assumptions

Concepts 5260-3, -4, -5, and -7 are concerned with impact attenuation provided by discrete pads or legs and shock struts. The landing dynamics for a space vehicle concept utilizing an internal, crushable, energy-absorbing system was performed for IBM solution. This solution includes the effects of residual vertical and lateral velocities at impact, vehicle orientation at impact, surface slope, and the geometrical and mass distribution properties of the vehicle. The equations described the motion during landing, the stability and final position of the vehicle, and the amount of energy absorbed by the internal crushable structure. The landing dynamics program
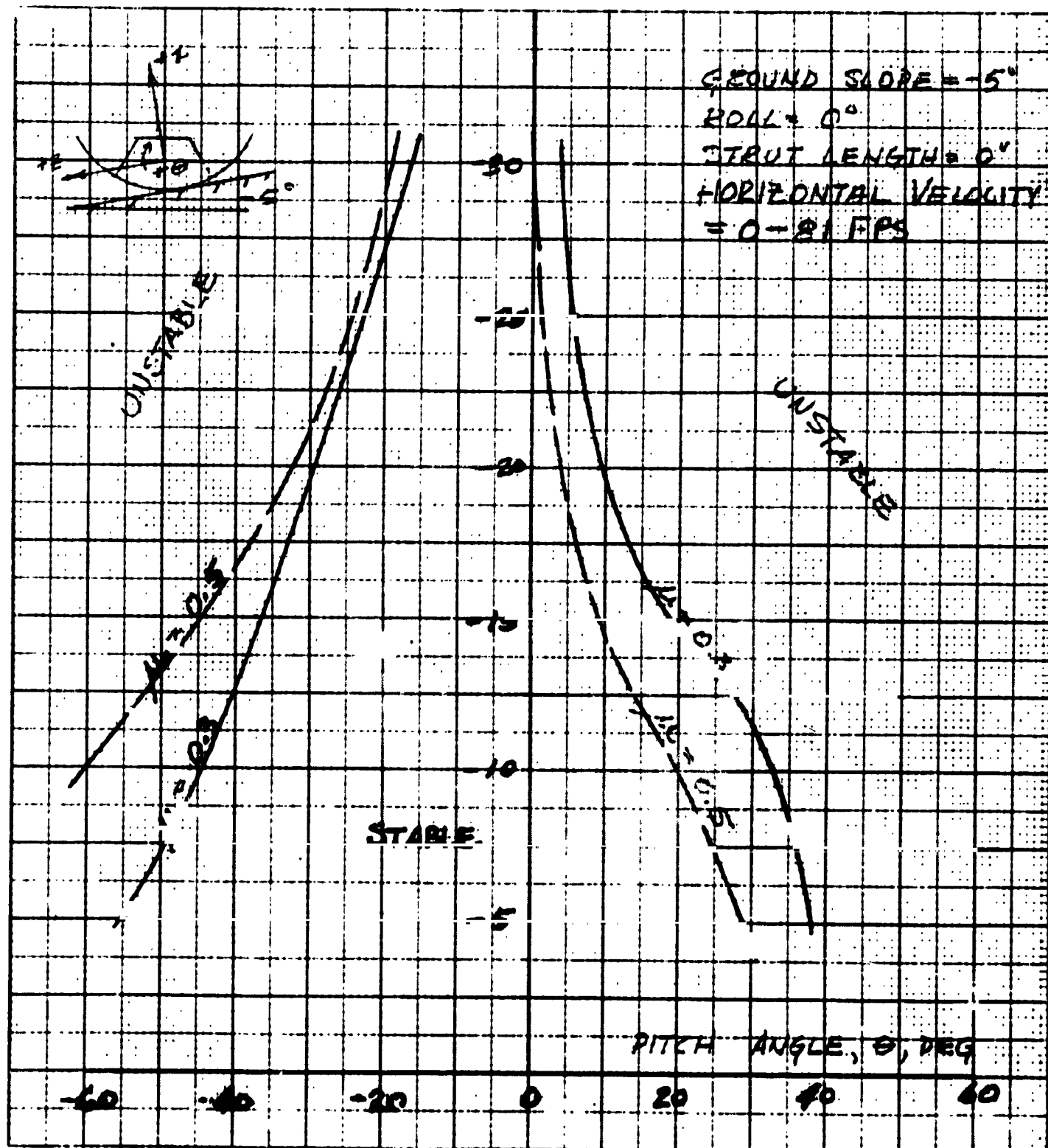
Initial Normal Velocity $\dot{x}$, fps

Figure 22　Stability Envelope for Deployable Heat Shield with Skids--Zero Strut Length
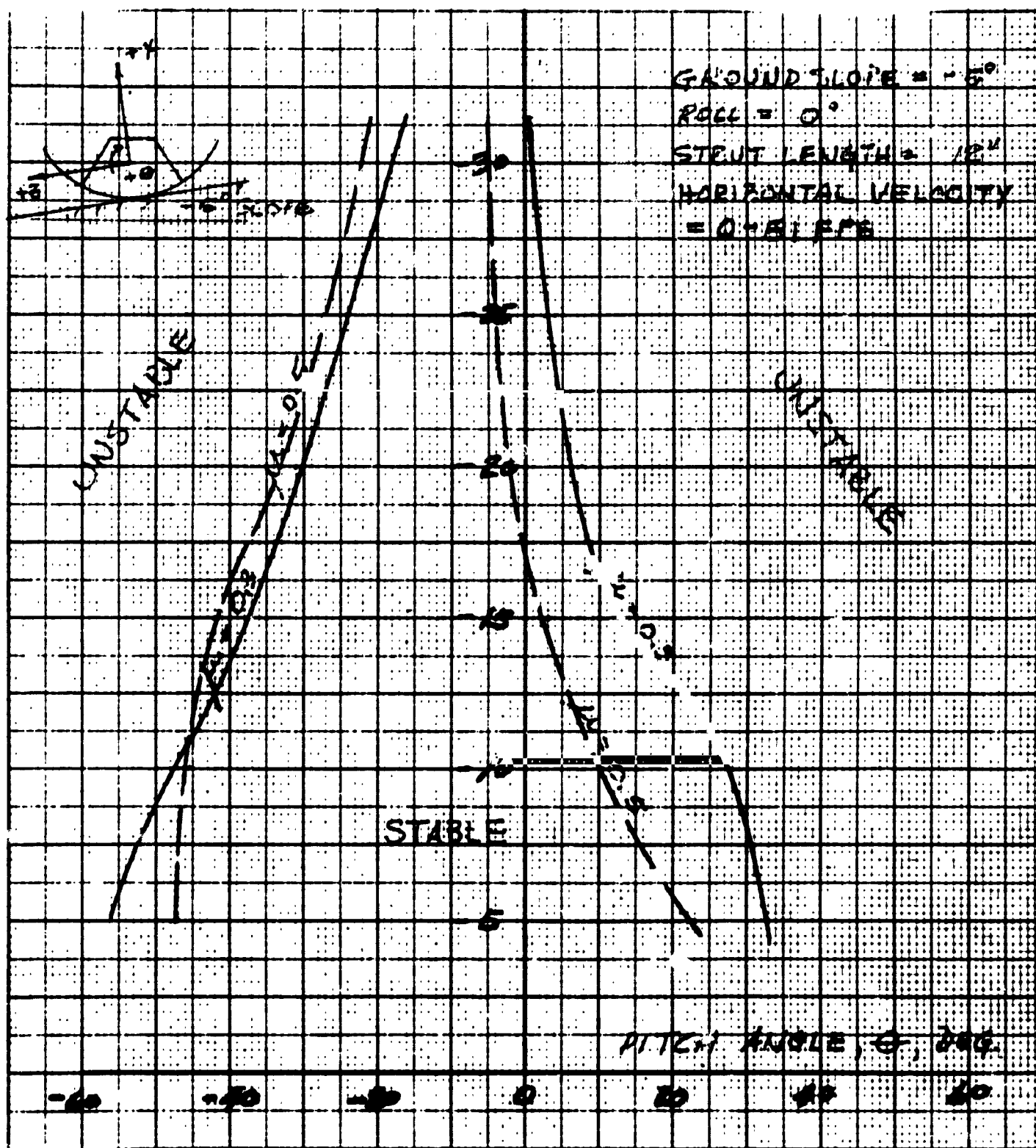
Figure 23   Stability Envelope for Deployable Heat Shield with
Skids--12" Strut Length

was used to define the combinations of vertical and lateral velocity and the lunar slopes for which the vehicle is stable.   The analytical program was substantiated by a series of laboratory drop tests performed upon a vehicle which s mulated the dynamic characteristics of the Surveyor spacecraft. These tests confirmed the results of the IBM program. The program is described in detail in References 4, 5, and 6.

The program is based on the conditions that the landing system can be simulated with a set of legs which deform along a certain direction, and that only these legs contact with surface.   In the computer the dynamics are handled in three dimensions using massless legs and six degrees of freedom for the vehicle. Using small time increments, the accelerations and velocities are integrated to produce new velocities and positions. The forces are calculated using the strength characteristics of the legs and assuming a constant coefficient of friction between legs and the earth.

Stabiliity of Concept 5260-3 Deployable Heat Shield/Four Legged Gear

The stability analysis of the four-legged gear showed that for the strut characteristics considered the design is stable for all combinations of horizontal and vertical velocity at touchdown.

In addition to the impact attenuation and stabilizing effect of the shock struts, Concept 5260-3 uses the idea that the trailing leg "catches" the soil while the forward leg "planes" over the top of the soil. The physical charac-teristics of the disks on the soil are nearly impossible to analyse and use, so the only discussion will be qualitative. The concept is sound except that some details will have to be refined:

1. Since there is a human tolerance on accelerations in the lateral direction, the legs will either have to be attenuated laterally or the shape of the disks changed to limit the lateral forces. If the trailing legs impact first and are allowed to break off, there might be enough residual angular velocity to overturn the craft.

2. If the vehicle were to impact leading leg first, it must be necessary to eliminate any possibility of high leg penetra-tion ar.d increased lateral force. In this case a high horizontal velocity will cause immediate overturning. Low stroking forces on the legs, larger areas for the disks, and/or an insurance of a hard surface will be necessary.

3. If the surface were too hard and the system had elastic properties, the disks would have marginal effectiveness and the stability would be no better than simple pads on the legs. (See Concepts 5260-4 and -5).

Stability of Concept 5260-5 Six Segment Hinged Heat Shield

This concept was stable for horizontal velocities up to 100 F. P.S., vertical velocities up to 20 F.P.S., ground slopes of 5 degrees, parachute

swing of $\pm$ 10 degrees, a friction coefficient of 0.5, and any roll orientation. It was assumed to be suspended nominally at zero pitch and yaw.

Stability of Concept 5260-4 - Four Segment Translated Heat Shield

This case was even more stable than Concept 5260-5 under the same initial conditions.

Stability of Concept 5260-7 - Tricycle Landing Gear

This concept has a very directionally sensitive stability envelope. Figure　24　shows the limit of stability for horizontal velocity and the orientation of the velocity relative to the vehicle. The surface slope of 5 degrees was placed so the vehicle was always traveling downhill. The most stable direction of travel is with the escape hatch forward. It should be noted that small changes from this attitude decrease the stability.

ANALYSIS OF OTHER DESIGN CONCEPTS

The stability analysis methods described above are not applicable to design concepts 5260-6 (Extended Heat Shield/Air Bag) and 5260-8 (Implanted Anchor).

The air bag concept, which was only marginally stable for the Mercury Spacecraft, is unsatisfactory for the MISDAS design velocity envelope. In fact, it is less stable than the basic Apollo design.

The implanted anchor concept can prevent only one type of overturning, i.e., with this velocity in the +Z direction or zero roll. However, the vehicle is presently very stable in this direction with no devices. In the other direction, 180 degree roll, which has marginal stability to begin with, the anchor line will be very detrimental to stability. If the system were placed on the +Z side of the command module, a significant improvement will occur for the 180 degree roll case, but a problem will occur for the zero degree roll case when the capsule overruns the anchor line.
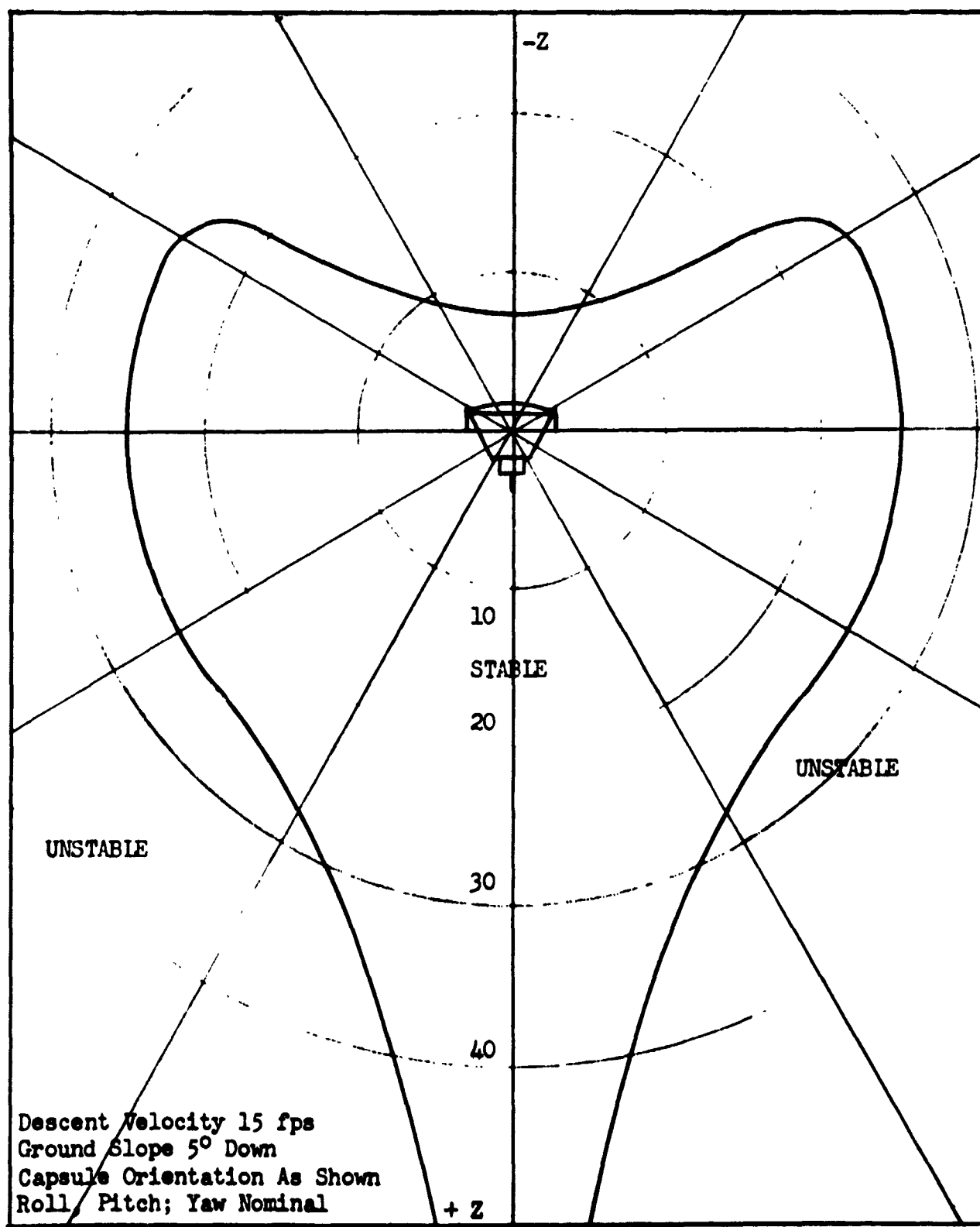
SID 65-1205

Figure 24   Stability Envelope for Tricycle Gear

PRELIMINARY STRUCTURAL EVALUATION

Limited structural analyses were conducted for the design concepts that possess acceptable landing stability. The objectives of the structural analysis were to determine the weight, size, and materials for the impact systems and to identify the requirements for reinforcement of the Apollo heat shield and structure. Where several concepts had equivalent structural characteristics, only one analysis was performed.

In accordance with the established design criteria described on pages 12 to 15, a common set of loading conditions was used for all concepts studied. The loads were based on the kinetic energy generated with a vertical velocity of 15 feet per second and an attenuation stroke of 1 foot. This produces total vertical impact load of 63,000 pounds to be divided among the impact attenuators. If, as in the case of the tricycle landing gear, a touchdown can occur which puts high loads on one or a group of attenuators, there may not be space available for a long enough actuator stroke to get the required load attenuation. In this case, additional structure is required.

TABLE 1

MISDAS TOTAL WEIGHT AND VOLUME COMPARISON

Concept	Description	Weight (lb.)	Volume (Cu. Ft.)
5260-1	Deployable Heat Shield/Chordwise Extended Skids	1300	1.6
5260-2	Deployable Heat Shield/Radially Extended Skids	1960	3.2
5260-3	Deployable Heat Shield/Four-Legged Gear	620	3.6
5260-4	Four-Segment Translated Heat Shield	710	2.2
5260-5	Six-Segment Hinged Heat Shield	610	1.6
5260-6	Extended Heat Shield/Air Bag	*	*
5260-7	Tricycle Landing Gear	1200	8.6
5260-8	Implanted Anchor	410	1.4

*No analysis - concept unstable.

Table 1 shows the total weight increment associated with each of the eight concepts under consideration. The weights shown include landing skids, actuators, impact attenuators, supports, controls, and modification to the Apollo structure and heat shield. This table shows that one concept can meet the target weight of 3.5 per cent of the 14,000 pound spacecraft landing weight, or 490 pounds (Reference page 12):

- 5260-8   Implanted Anchor

The following concepts are clearly overweight, and can therefore be eliminated from further consideration:

- 5260-1   Deployable Heat Shield/Chordwise Extended Skids

- 5260-2   Deployable Heat Shield/Radially Extended Skids

- 5260-7   Tricycle Landing Gear

The following concepts are slightly above the target weight. They will be considered acceptable, because a more refined analysis could bring their weights down to within the target figure:

- 5260-3   Deployable Heat Shield/Four-Legged Gear

- 5260-4   Four-Segment Translated Heat Shield

- 5260-5   Six-Segment Hinged Heat Shield

For the introduction of loads into the inner structure, the Apollo has a total of eight longerons. Figure 25 shows the location of the longerons and their limit design loads. Since they are located off-axis, it was assumed for the Phase I analysis that all concepts would require the addition of new longerons wherever any attachment was required to the inner structure. Figure 26 shows the critical design ultimate loads for the Apollo Command Module Inner Structure.

CONCEPT 5260-1, DEPLOYABLE HEAT SHIELD/CHORDWISE EXTENDED SKIDS

The largest weight item in this concept is the combination of skid and housing. Figure 27 shows the results of a parametric analysis of the skids, indicating the required width versus the actual load for 1.5 and 2.0 inch thick high-strength steel (FTY = 250 KSI and 300 KSI) (Reference 1). These values can be obtained with the advanced Maraging steels. Steel was chosen for the skid material to minimize skid deflection. The deflection, which is an inverse function of E (Young's modulus) of the material, has a major effect on the spacecraft stability. On a weight-strength basis the Maraging steel is equivalent to the titanium alloys which have approximately one-half of E of steel (Reference 1) and therefore twice the deflection.

Figure 25   Apollo Longeron Design Limit Loads
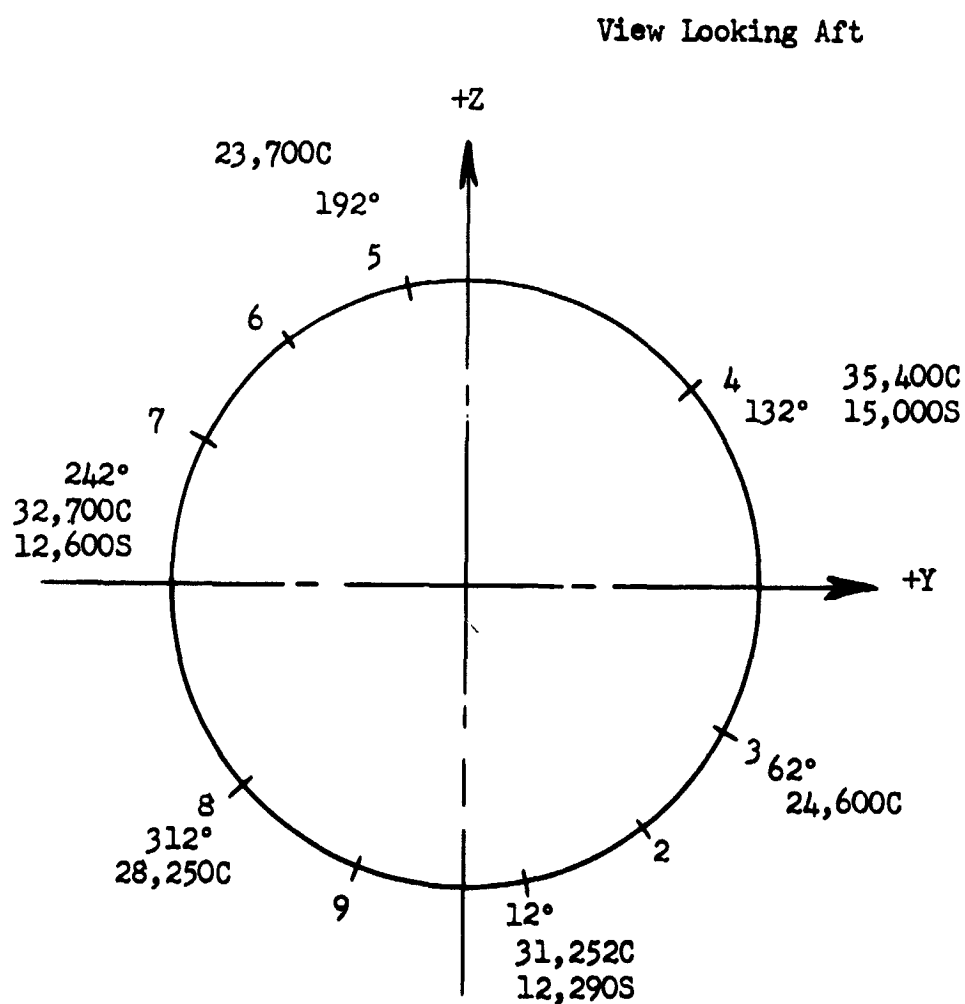
Longerons 2, 8, & 6 are equal strength
Longerons 4, 1, & 7 are equal strength
Longerons 3 & 5 are equal strength
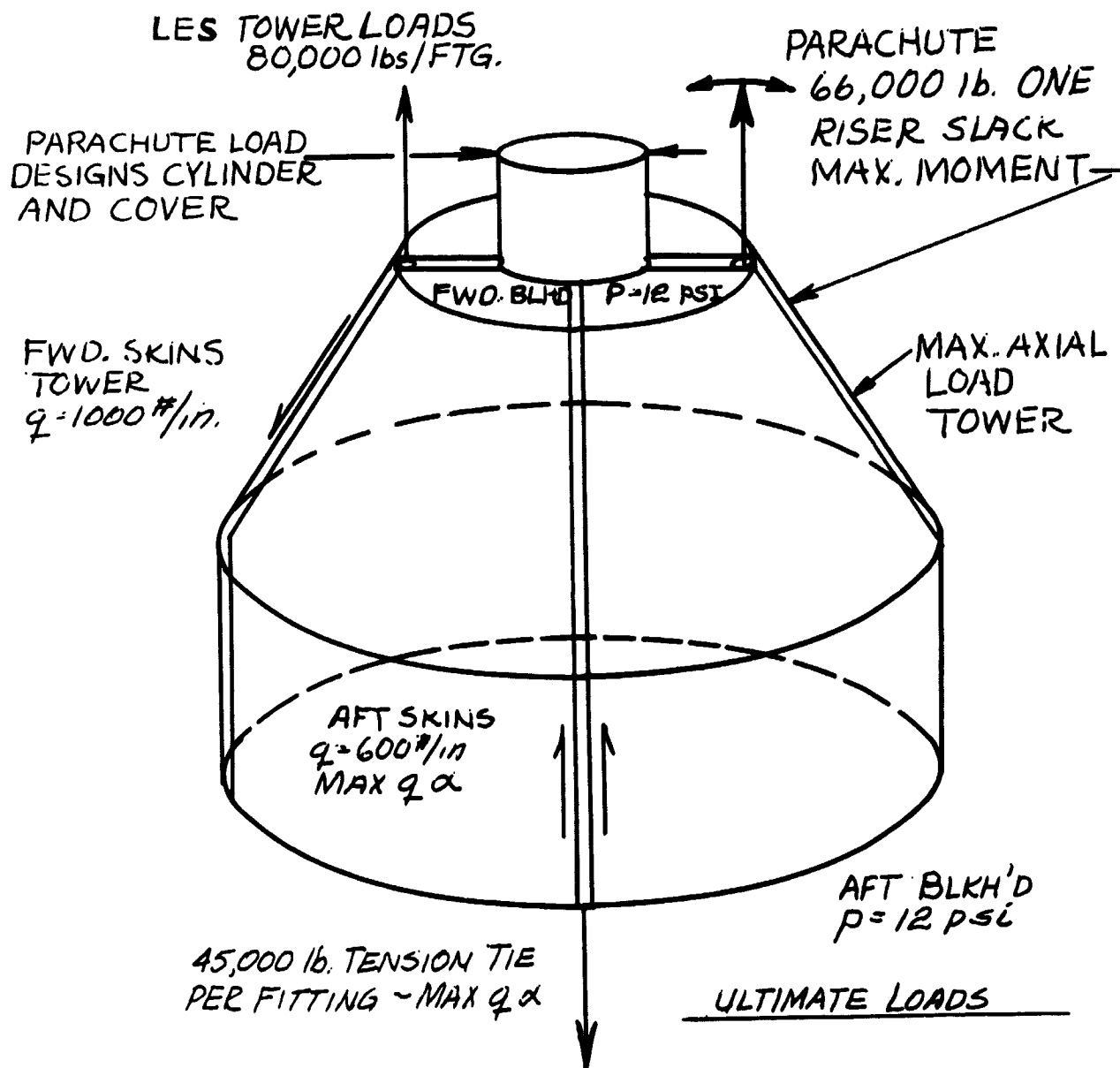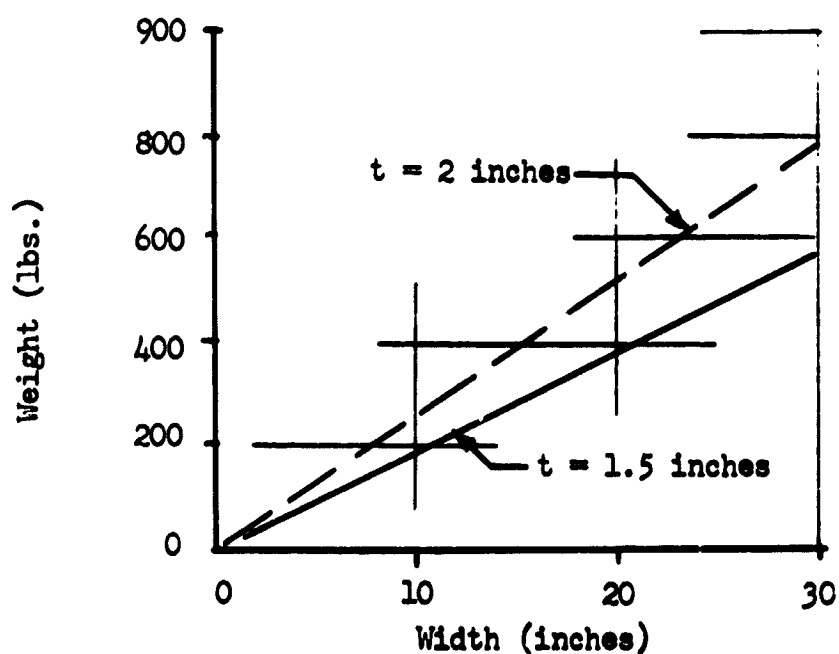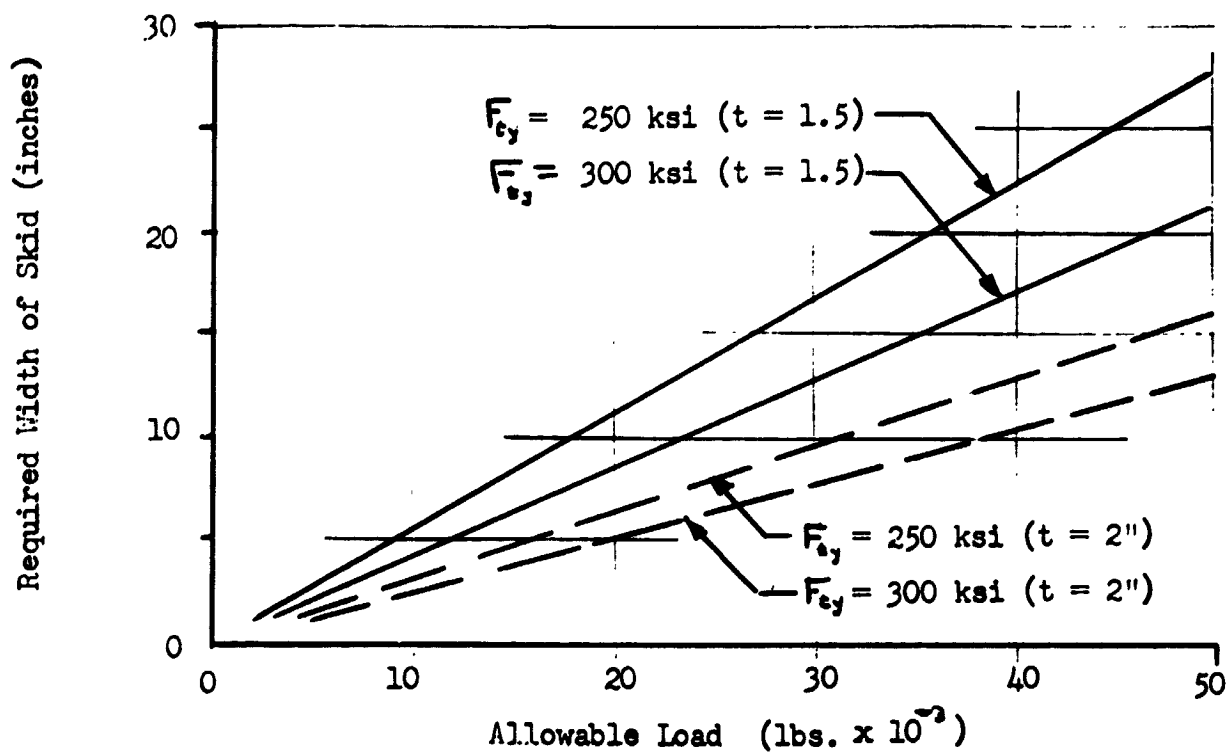
SID 65-1205

Figure 26   Apollo Command Module Design Loads

Figure 27   Weights of Extended Skids

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The system weight breakdown is as follows:-

Heat shield modification	30	lb.
Structure modification	30	
Actuator/attenuator installation	100	
Impact spring installation	140	
Skid installation	1000	
Total weight	1300	lb.

These weights were calculated for four tapered skids, five inches wide and two inches thick at their base. Their load carrying ability is 46,000 pounds at a point 53 inches from the spacecraft with a resultant deflection of 20 inches. This loading is somewhat conservative. A precise calculation of the skid loading should be based on a stability analysis utilizing the load-deflection curve of the skids. This is beyond the scope of the stability analysis of Phase I of this study.

The skid housings were designed to an initial pressure of 1000 psi with a straight line decay curve to full extension. This gives a total force of 10,000 pounds for piercing of the heat shield. The housings can be designed as the main structural members of the modified heat shield and permit a weight saving in this area.

CONCEPT 5260-2, DEPLOYABLE HEAT SHIELD/RADIALLY EXTENDED SKIDS

The structural design requirements and features of this concept are in general, the same as for Concept 5260-1. The radial arrangement of the skids leads to some detail differences in the skid loading and in the attachment to the spacecraft. The system weights for 5260-2 are:-

Structural modification	30	lb.
Actuator/attenuator installation	400	
Skid inatallation	1500	
Total weight	1930	lb.

CONCEPT 5260-3, DEPLOYABLE HEAT SHIELD/FOUR-LEGGED GEAR

The weight figures for this concept are based upon a coefficient of friction of 1.0 between the disk and the ground. This gives a horizontal force of 15,750 pounds which produced bending in the shock strut. Testing in varying soil conditions would be required to determine if this force could become greater as the disk tends to burrow in the ground.

Longerons are required to distribute the loads applied at the upper attachments of both the vertical and horizontal struts into the inner structure skins. Kick loads can be reacted by existing structure, i.e. the inner upper beam and the aft pressure bulkhead.

The deployed aft heat shield acts as a horizontal shear beam causing all of the lateral struts to act together. Reinforcement is required around

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the cutouts in the heat shield. An initial high force in the deployment struts is required to insure that the disk will break free of the heat shield to assure overcoming any adhesion that may be caused by the by-products of ablation.

The system weight breakdown is as follows:-

Heat shield modification	20 lb.
Structure modification	30
Disk skids	120
Attenuator installation	450
Total weight	620 lb.

CONCEPT 5260-4, FOUR-SEGMENT TRANSLATED HEAT SHIELD

This concept requires major modifications to the Apollo inner structure. The loads generated during impact are absorbed by the shock attenuators into the lower sidewall skins by the addition of longerons. However, as the heat shield segments overhang the attenuator a kick load is generated which must be reacted by the lower pressure bulkhead. Additional shear beams are required in the interior of the shell to transfer the loads to the side skins. This will require repackage of the interior spacecraft components.

As shown on the drawing, the heat shield is separated into five sections, four that move and one fastened directly to the inner structure bulkhead. This requires the inner bulkhead to react the air pressure loads of reentry. Furthermore this attachment could provide a direct heat path from the heat shield to the interior structure. Thermal protection is required to prevent overheating the aluminum alloy pressure bulkhead structure.

The system weight breakdown is:-

Heat shield modification	310 lb.
Thermal protection	40
Structure modification	130
Segment actuation system	80
Attenuation system	150
Total weight	710 lb.

CONCEPT 5260-5, SIX-SEGMENT HINGED HEAT SHIELD

This concept, like 5260-4, uses segments of the heat shield for ground skids. However, the heat shield sections do not translate but are hinged to pivot downward.

The shock attenuators are similar to the 5260-4 design, and the same longerons are required. In Concept 5260-5, the fixed part of the heat shield can be made strong enough to react the loads of impact. Thus, the undesirable feature of 5260-4—the heat shield support from the pressure bulkhead—

-59-

is not required. The system weight breakdown is given below:-

Heat shield modification	360 lb.
Structural modifications	100
Attenuation system	150
Total weight	610 lb.

CONCEPT 5260-6, EXTENDED HEAT SHIELD/AIR BAG

Since this concept was found to be unstable, no structural analysis was performed.

CONCEPT 5260-7, TRICYCLE LANDING GEAR

This concept is similar to the gear designed for the Gemini/paraglider landing tests. The structural analysis and weight calculations were modified to reflect the difference in spacecraft gross weight.

The critical rear gear loading condition for forward flight is in a nose-high attitude, and limits the attenuator travel to 9 inches. The resulting landing gear load is 53,000 pounds on each rear skid.

The maximum load on the forward skid is 31,000 pounds, and is the result of three-gear contact plus an increment due to rotational kinetic energy. The Apollo structure in area of the forward gear attachment was designed to react the LES tower loads and the parachute loads. It does not require reinforcement to carry the gear loads.

To permit the aft gears to be stowed, extremely short coupling of the mechanism is required. The geometry shown on Figure 20 results in a load of 248,000 pounds introduced into the inner structure. The extensive modifications required to accommodate this load imposed a very severe weight penalty on the system.

The system weight breakdown is as follows:-

Heat shield modification	40 lb.
Structure modification	190
Nose gear installation	340
Main gear installation	630
Total weight	1200 lb.

CONCEPT 5260-8, IMPLANTED ANCHOR

This concept reacts the impact loads directly on one extendable portion of the heat shield. The inner structure in this area requires a general strengthening to permit introduction of this 63,000 pound loading. Preliminary analysis shows that a load of 10,000 pounds in the cable assembly can prevent spacecraft overturning. The calculated weights are based on

this figure. Testing would be required to verify whether this figure can be maintained in varying soil conditions.

This concept was not considered further for in a backward landing mode the cable could become deployed beneath the vehicle and cause it to tumble.

An estimated weight breakdown is as follows:-

Heat shield modification	75 lb.
Structural modification	150
Anchor installation	125
Attenuator installation	60
Total weight	410 lb.

CONCLUSIONS AND RECOMMENDATIONS

For the selection of the concept to be studied in Phase II of the program, the concepts were examined as to their ability to satisfy the design criteria:

- The system must not turn over in landing with a vertical velocity up to 15 feet per second and a horizontal velocity up to 81 feet per second in the forward direction, and a horizontal velocity in an emergency condition of 51 feet per second in any direction.

- The system must absorb landing impact energy without subjecting the crew, structure, or payload to excessive accelerations.

- The system must fit within the limited space available between the Apollo heat shield and inner structure.

- The system should be of minimum modification and satisfy the standards of simplicity, reliability and minimum weight. The target weight figure is 3.5% of the 14,000 pounds gross weight.

Based upon the stability evaluation, Concept 5260-6, Extended Heat Shield/Air Bag and Concept 5260-7, Tricycle Gear were eliminated. Concept 5260-6 is unstable for all values of horizontal velocity. Also to prevent bouncing, blowout plugs are required. Past investigations into this area has shown the operation of these to be marginal. Concept 5260-7 can meet the horizontal velocity requirement in only the forward direction. Furthermore, Concept 5260-7 exceeds the weight requirement by a large factor and requires large volumes for stowage in the forward heat shield and parachute compartments.

Concept 5260-8 is not recommended because of the uncertainties of the anchorage due to varying soil conditions and the possibility of the spacecraft turning over if the cable is caught beneath the vehicle. based on the structural analysis, Concepts 5260-1 and 5260-2, which utilize extended skids, were eliminated for excessive weight.

The three remaining concepts, 5260-3, -4, and -5, all have satisfactory stability characteristics and all have weights reasonably close to the target figure of 490 pounds. They were evaluated for relative design efficiency, compatibility with Apollo design, reusability, and ability to withstand higher rates of descent.

Concept 5260-3 Deployable Heat Shield/Four Legged Gear, depends for its operation on its ability to plane on the forward leg and dig in on the aft legs. It would require extensive testing in varying soil conditions to insure its stability under all landing conditions.

Concept 5260-4, Four Segment Translated Heat Shield and Concept 5260-5, Six Segment Hinged Heat Shield are similar in principle. The translated heat shield gives a larger landing area and is thus more stable against turnover. However, the six segment is more than adequate to meet the design criteria.

Concept 5260-5 does not call for redesign of the aft pressure bulkhead. The aft heat shield would require a complete redesign and testing for its integrity under atmospheric reentry conditions. The effect of structural discontinuities in the aft heat shield ablative system on the thermostructural integrity of the heat shield must be evaluated and verified by test.

Additional longerons will be required on the inner structure sidewalls for the attachment of the attenuators. During Phase II, the existing longerons will be examined to see if with minor modifications they may be utilized at some of the attach points.

This concept seems to be readily adaptable to the higher rates of descent. As a result of the stability analyses conducted in Phase I, it became evident the suspension angle should be changed from 27° to a nominal 0°. When either of the concepts using extended skids touches down in the backwards landing mode, a rotational velocity is imparted to the vehicle which causes it to turn over in any attitude except for very small angles. Furthermore, the legged type systems require a very complicated mechanical system to assure stability at high touchdown angles. Otherwise the resultant spacecraft velocity vector will be practically parallel to the leading shock strut, subjecting the structure to excessively high impact loads. These loads would require strengthening to the point of complete redesign. The change in angle is required for land landing only. The 27° angle would have to be maintained to satisfy Apollo water criteria. Therefore, a two position parachute lanyard is suggested. It can be provided by a loop in the lanyard held by an explosive device, holding the spacecraft at a 27° angle for water landing. If the landing is to be made on land, the device would be actuated permitting the vehicle to settle to the 0° angle.

The system selection tradeoff was based on the rating factors shown on page 10. The results of the tradeoff are presented in Table 2.

Based on this tradeoff, Concept 5260-5, Six-Segment Hinged Heat Shield with a suspension angle of zero degrees, is recommended for further study in Phase II. The design has superior landing stability, acceptable system weight, and compatibily with the other design criteria.

Table 2   System Selection Tradeoff

Concept 5260-	1	2	3	4	5	6	7	8
a. Weight			14	13	15			
b. Volume			4	7	10			
c. Stability			15	25	25			
d. Reliability & Efficiency	Over weight	Over weight	10	5	15	Unstable	Over weight	Unstable
e. Modifications			5	0	10			
f. Reusability			10	5	10			
g. Required Refurbishment			10	5	5			
h. Effect of Increased Rate of Descent			4	0	5			
Total	−	−	73	60	95	−	−	−

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3. <u>Structures Manual</u>, S&ID 543-G-11, Space & Information Systems Division, North American Aviation, Inc.

4. <u>Dynamic Analysis of Lunar Alightment</u>, STR-78, Space & Information Systems Division, North American Aviation, Inc.

5. <u>Parametric Studies of the Landing Stability of Lunar Alightment Vehicles</u>, STR-79, Space & Information Systems Division, North American Aviation, Inc.

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